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THE COMPARISON OF GALVANOMETERS AND A NEW TYPE OF FLAT-COIL GALVANOMETER.

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THE term, galvanometer, is applied to electrical instruments of protean form and uses. Any article upon the subject "galvanometers," to have moderate length, must be written from a restricted view-point, and deal with instruments of a specific type. In the following pages, we shall make a few general remarks upon galvanometer-design, and describe a basis upon which the merits of different galvanometers may be compared in certain of their prominent features. We shall then describe the form, qualities, and adaptability of a comparatively new type of moving-coil galvanometer which has not been fully or adequately described heretofore. We shall add a table giving comparisons between galvanometers of different kinds and by different makers.

We may state, at the outset, that "sensibility" is not the sole requisite of a good galvanometer. Nor will the solution of the general equation of motion of a movable system, possessed of a moment of inertia, a coefficient of torsion and a damping factor, give much aid in the design or in the selection of a good galvanometer. The goodness of a galvanometer is to be judged by its adaptability to the work assigned to it as well as by the performance of which it is capable. The problem of estimating

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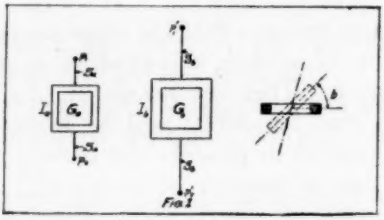
what, in a galvanometer, is essential to usefulness must be attacked by methods which experience in use and design teach, as well as by considerations of general principles. The designer must add to his experience, very clear conceptions of what the instrument will be called upon to do.

Every galvanometer design, by necessity, is a series of compromises. No one instrument can possess all the qualities, in full measure, desired. One's experience and judgment must guide to a proportionate selection of such diverse qualities as the following: sensibility, short period, accurate return to zero, tensile strength of suspension, freedom from easy disturbance by external influences, such as air currents, accurate balancing of the system to give stability against vibrations, proportionality in the deflections, strength and uniformity of the magnetic field, clearness and ease of reading the scale, freedom from magnetic impurities in the system of moving-coil instruments, variable or fixed damping to secure aperiodic return to zero, proper coil clearance for free motion and ease of adjustment, arrangements to facilitate transportation, freedom from parasitic currents resulting from internal thermo-electric forces, proper resistance of coil and suspensions, permanence of the galvanometer constant, small temperature coefficient, provisions for easy inspection of system and replacing of suspensions, high insulation where required, facility in mounting, adaptability to general classes of work as well as to a specific service, ease in construction, graceful appearance, and a construction which is moderate in cost. Besides such features in practical design, one must well understand the fundamental principles which underlie every galvanometer, if the best possibilities of the instrument are to be secured. As a beginning in design or in selecting an instrument for use, particular qualities, needed for a particular service, should have special attention. No universally serviceable instrument of this class, equally good for all kinds of work, ever was or ever will be constructed.

These preliminary remarks hint at the scope of the subject of galvanometer construction, and emphasize the necessity one is under, if he would pass judgment upon the merits of a galvanometer, to have first a clear conception of the use for which the instrument is intended. A galvanometer, admirably adapted to show the readings of a bolometer giving the energy distribu-

tion in the spectrum would make a poor lecture-room instrument for general demonstration purposes, nor, would it be suitable to put into students' hands for Wheatstone-bridge work.

A common basis for comparison of the respective worths of galvanometers of diverse pattern, in respect to the single quality which has been termed "the figure of merit" may be reached with a fair degree of satisfaction. A clear physical conception of this feature and what it means, will be a useful preliminary to any estimation of the worth of any current-measuring instrument. We may touch with advantage, therefore, upon this question, before describing the form, qualities, and uses of the special type of galvanometer, to describe which, is the leading object of this article.



Let Fig. 1, G_a and G_b represent, diagramatically, two systems of any type of moving-coil galvanometer. Let these systems be held by suspensions, S_a and S_b, attached at points P_1, P_2, and P'_1, and P'_2.

Suppose the coil-winding of each is on a metal frame of such cross-section and conductivity that, when the system rotates in the magnetic field, its return to zero from a deflection is just aperiodic in virtue of the currents induced in the frame. To have this condition always fulfilled, one may conceive the conductivity of the frame to vary whenever the moment of inertia of the system, the torsion of the suspension, and the strength of the magnetic field are varied. This premised, let such a current pass through each system that it will be rotated through a standard angle, b, which may be made always the same by varying the strength of the current. Evidently the current which will be required to produce this deflection will depend upon many factors, chief among which are the strength and uniformity of the magnetic field, the torsional force of the

suspension, the length and number of turns in the coil, and the degree of freedom from magnetic impurities in the system.

The system, starting from rest, will require a certain time, T, after the current is applied, to complete a certain fractional part of its aperiodic deflection. To be definite, assume that the deflection is practically completed, when it has reached within one-twentieth per cent. of its final deflection. This time, T, will be, for all purposes of practical computation, the same as the time of a complete oscillation of the same system undamped. If I is the moment of inertia of any galvanometer system, then the square of its time of deflection, as above defined, or of a complete oscillation, if undamped, is proportional to this moment of inertia—or

$$T^2 \propto I.$$

Now so arrange matters that the same current through each of the two systems, G_a and G_b, will produce in each the standard angular deflection, b. Then the *sensibility*, S_m, of each system is the same and this sensibility will be inversely proportional to the current required to produce the deflection. If, however, the system G_a has a moment of inertia (I_a), and the system G_b a greater moment of inertia (I_b), then G_a will reach its standard deflection in a shorter time than G_b. The ratio will maintain that,

$$\frac{T^2_a}{T^2_b} = \frac{I_a}{I_b}.$$

By hypothesis, the sensibilities; that is, the currents required through each, to produce the standard deflection, are equal. Since, however, G_a deflects in a shorter time than G_b its suspension might be weakened until its time of deflection equals that of G_b. But with a weaker suspension it will take less current to produce the standard deflection. Hence, with equal times to make the standard deflection, the system G_a is more sensitive than the system G_b.

Conversely, to make G_b deflect the same amount in the same time as G_a, its suspension must be stiffened, and with a stiffer suspension, it will require more current than G_a for the standard deflection. In this respect it is a less sensitive galvanometer than G_a.

As it is always possible to vary within wide limits the tor-

sional force of a galvanometer suspension, a galvanometer, which is quick but not sensitive, can be made more sensitive at the expense of quickness by changing its suspension, and a galvanometer which is slow but sensitive, can be made quicker at the expense of sensibility. If we call S_m the sensibility of a particular galvanometer, and T its period, then the product, $S_m \frac{1}{T^2}$, cannot be increased by changes of the above character. We shall call this product proportional to the *useful sensibility* of any particular galvanometer and write

$$U \propto \frac{S_m}{T^2}. \tag{1}$$

By T we must understand the time of a complete oscillation, if the galvanometer is undamped, or the time it takes to reach within one-twentieth per cent. of its final deflection if it is damped magnetically to be just aperiodic.

For practical purposes of comparison of galvanometers, the time may be considered the same, for the instrument in either of these conditions.

While the sensibility, S_m, is inversely proportional to the current needed for the standard deflection, this current, if everything else remains the same, will be less as the number of turns in the coil is increased. Of two galvanometers, which are to be used on the same *constant-current* circuit, and which are alike in all features, except in respect to number of turns, that one which has the more turns will be the more sensitive. We can call, therefore, the sensibility of a galvanometer, for use on a constant-current circuit, a quantity which is proportional to its number of turns, and inversely proportional to the current required to produce a standard deflection. Or

$$S_m \propto \frac{n}{i}. \tag{2}$$

Hence, its useful sensibility is

$$U \propto \frac{n}{iT^2} \propto \frac{S_m}{T^2}. \tag{3}$$

To increase the number of turns we may proceed in either or both of two ways: the size of the insulated wire may be diminished and the same winding space be filled, or the wire

may be kept the same and the dimensions of the cross-section of the winding channel may be increased. By the first method the moment of inertia of the system remains nearly the same. It would remain exactly the same, if in altering the size of the wire no alteration were made in the density of the coil by changing the ratio of insulation to wire through a change of wire size. By the second method, the moment of inertia, and hence T^2, will be changed unless the length of the turns are also diminished in a proper proportion. We have seen that U, the quantity which we have called the useful sensibility of a galvanometer, cannot be changed by changing the torsional force of its suspension, but that it may be changed by changing the coil winding. Thus, in changing n, if the moment of inertia only is changed, T^2 will be changed and U will be changed, because the period changes, but, if n is changed in such a manner as not to change the period, then U will change again, because S_m, the sensibility, changes. If n is changed in such a way as to vary both S_m and T^2, U will still change unless the exceptional condition is met, that n so changes that $\frac{n}{T^2}$ remains constant. We conclude, by the above line of reasoning, that *useful sensibility* is a constant property of a particular galvanometer with a particular winding, but a quantity which varies when the coil windings are changed. But if we divide the useful sensibility by the number of turns in the coil and write

$$F \propto \frac{U}{n} \propto \frac{S_m}{n T^2} \propto \frac{1}{i T^2} \qquad (4)$$

we obtain the new quantity, F, which has been designated the "figure of merit" of a galvanometer.

The figure of merit of a galvanometer, is a kind of "specific quantity" which attaches to every galvanometer. As the useful sensibility of a galvanometer cannot be improved by changing the torsional force of its suspension so also we cannot increase the figure of merit of a galvanometer by changing either its suspension or the turns in the winding space of its coil. A galvanometer with a certain "figure of merit" is potentially, so to speak, capable of having a certain chosen period with a certain accompanying sensibility and number of turns, or a

certain chosen sensibility with a certain accompanying period and number of turns, but to increase the figure of merit, changes must be made in the field-strength or in the proportioning of the galvanometer parts. As "figure of merit" attaches as a specific property to every galvanometer, it serves in a useful way to compare the intrinsic worths of various types of instruments. If, however, we wish to compare the figures of merit of different galvanometers, we cannot do so practically by using the expression above in its present form, because there is no easy way of counting the number of turns in the coils after the galvanometers are built. It is necessary, therefore, to find how the resistance of the coil is related to its number of turns, for this is a quantity easily measured. To do this, write

$$R = \frac{4 l_1 \rho n}{\pi W^2} \tag{5}$$

where l_1 = length of mean turn,

W = diameter of wire,

ρ = specific resistance of wire.

If S = cross-section of channel and

d = double thickness of wire insulation, then,

$$n = \frac{S}{(W+d)^2} = \frac{\pi S}{\pi W^2 + 2\pi W d} \tag{6}$$

the term πd^2 being neglected, as being very small.

From (6) we derive $\pi W^2 = \frac{\pi(S - 2Wnd)}{n}$, and putting this value of πW^2 in (5) we obtain,

$$R \propto \frac{n^2}{S - 2Wnd}. \tag{7}$$

Solving this quadratic and using the positive sign before the radical, we obtain,

$$n \propto \sqrt{RS + R^2W^2d^2} - RWd. \tag{8}$$

When this value of n replaces n in the expression (4) for F we have as the resulting expression, not involving n, for the figure of merit of a galvanometer,

$$F \propto \frac{S_m}{T^{\frac{1}{2}}[(RS + R^2W^2d^2)^{\frac{1}{2}} - RWd]}. \tag{9}$$

Except in cases where galvanometers wound with coarse wire are compared with galvanometers wound with very fine wire, the thickness, d, of the insulation may be neglected. We may consider S constant and we have when we do this,

$$F \propto \frac{S_m}{T^2\sqrt{R}} \propto \frac{U}{\sqrt{R}} \propto \frac{1}{iT^2}. \tag{10}$$

$\frac{S_m}{T^2\sqrt{R}}$ is the usual expression for the figure of merit of any galvanometer. In comparing galvanometers by it, the supposition is made that thickness of insulation is neglected and that the galvanometers compared are wound with wire of the same *specific resistance*. The specification which we shall adopt to define S_m is as follows:

With the scale at 1000 scale-divisions from the mirror, of a mirror galvanometer, the sensibility, S_m, is the number of megohms which must be in the galvanometer circuit so that with an E.M.F. of one volt in the circuit, there will result a deflection of one scale division. With this understood, we can write:

$$F = \frac{S_m}{T^2\sqrt{R}}. \tag{11}$$

A galvanometer would have, then, a unit figure of merit, if its time of a complete oscillation is one second, or which is practically the same thing, if its time of aperiodic return to zero within one-twentieth per cent. of its previous deflection is one second, and the resistance of its winding is one ohm, and when, with one megohm in series and one volt in circuit, its deflection, on a scale one thousand scale divisions from its mirror, is one division.

As this unit has received no name,we will call it, for convenience a *D'Arson*.

We can say, also in accord with the above definition of sensibility, that the sensibility is unity when one micro-ampere produces the standard deflection. Hence, if i_m = the micro-amperes in the galvanometer circuit,

$$S_m = \frac{1}{i_m}.$$

If E_m micro-volts are applied at the terminals of the galvanometer of resistance R, we have,

$$i_m = \frac{E_m}{R} \text{ or } S_m = \frac{R}{E_m}.$$

Putting this value of S_m in (11) gives:

$$F = \frac{\sqrt{R}}{E_m T^2}. \qquad (12)$$

The relation (12) defines the figure of merit of a galvanometer in terms of its resistance, period, and the number of microvolts applied at its terminals to produce the standard deflection.

As an example of the use of relation (11) suppose we have a galvanometer with a complete period of 5 seconds, a coil resistance of 400 ohms, and which deflects one scale division with one volt acting through 500 megohms, then its figure of merit is,

$$F = \frac{500}{5^2\sqrt{400}} = 1 \text{ D'Arson.}$$

If this galvanometer were given a longer period, by using a weaker suspension, its sensibility would be larger, but F would not be altered by this change. It is evident that the coil might be wound, using the same size wire, to a smaller resistance, but if this were done the mass of the coil would be less and hence T^2 would be smaller. Both of these changes would contribute to a greater figure of merit. On the other hand, a smaller resistance would mean a smaller number of turns which would reduce the sensibility and hence diminish the figure of merit. Thus it is always open to the designer, to so choose the winding and proportion the coil, and to so arrange the strength of the magnetic field and other factors that F shall be large. The success with which he does this determines in considerable measure the perfection of his design.

It must not be forgotten, however, that the number of D'Arsons possessed by a galvanometer is not necessarily a final measure of its fitness for actual service. It may possess faults of many kinds which more than offset a large figure of merit. Chief among such is zero shift, and magnetic impurities in

the system, which two, in fact, generally go together. There are also other common defects, as small coil clearance, inaccessibility of the parts, a poor optical system, an unproportional scale, a provoking tendency of the system to respond to small tremors, and a host of other minor defects which the user soon observes and condemns.

If it were not necessary to load a galvanometer system with a mirror, or a pointer for the purpose of reading the deflections, it would be possible by proper designing and by a great diminution in the size of the moving parts to realize an instrument which would possess an enormous figure of merit as compared with an ordinary moving coil galvanometer. This has in fact been done in the case of the Einthoven String Galvanometer, which has about 3000 times the number of D'Arsons of a good moving coil galvanometer using a mirror and scale. We are led thus to the general consideration of what are the possibilities of obtaining a great figure of merit for galvanometers of the deflection type.

In every galvanometer of this type we may consider the moment of inertia of its moving system as made up of two parts: One part is the moment of inertia which is contributed by the mirror, the pointer, or whatever device may be attached to the system which is required for reading the deflections of the instrument. We may make this reading device small but we cannot dispense with it altogether and preserve the instrument as a galvanometer of a type to which the name is ordinarily applied. Indeed there are many practical considerations which soon put a limitation upon a continual diminution of mass of these parts. The other part is the moment of inertia which belongs to the moving wire or magnets, which constitute the effective working element of the system. This part of the total moment of inertia can be modified at will by the designer with the object of making the figure of merit of the galvanometers large as possible. The question then arises, has the figure of merit a maximum value which the most skilful designing cannot exceed? If there were no "dead parts" attached to the system, for reading deflections, then, theoretically, a galvanometer could be given, by proper designing, an indefinitely great figure of merit. This realization is obtained practically in the Einthoven String Galvanometer. But as long as galvanometers

continue as instruments read with mirrors or pointers, there will be a theoretical maximum figure of merit which cannot be exceeded. This proposition may be supported as follows: Call I_t the moment of inertia of the entire moving system, I_s the moment of inertia of the portion of the system active in producing a turning movement, and I_r the moment of inertia of the "dead parts," *i.e.*, the mirror, or pointer which, from practical considerations is fixed in value, though chosen small as possible. In I_r must also be included the winding form, if there is one, and the stem or axis of the system. We shall now have:

$$I_t = I_s + I_r \propto T^2 \tag{13}$$

and expression (11) for the figure of merit becomes:

$$F \propto \frac{S_m}{(I_s + I_r)\sqrt{R}}. \tag{14}$$

Assume the galvanometer of the moving coil type, and, in modifying the design of its system, let the coil resistance be maintained constant. Then:

$$S_m = f(I_s). \tag{15}$$

This means that the sensibility of the galvanometer will be some function of that part of the moment of inertia which is active in producing a turning moment. For, the resistance being kept constant, a change in the number of turns, and hence in the moment of inertia of the winding, will modify the sensibility. Then we have:

$$F \propto \frac{f(I_s)}{I_s + I_r}. \tag{16}$$

In this expression, as F is modified by modifying I_s while I_r as well as the resistance, is held constant, we arrive at a relation which must hold in order that F shall be a maximum. Thus:

$$\frac{dF}{dI_s} = \frac{(I_s + I_r) f'(I_s) - f(I_s)}{(I_s + I_r)^2}. \tag{16}$$

The right hand member of (16) equated to zero gives:

$$I_s = \frac{f(I_s) - I_r f'(I_s)}{f'(I_s)} = \frac{S_m - I_r \frac{dS_m}{dI_s}}{\frac{dS_m}{dI_s}}. \tag{17}$$

As an example of the application of (17) suppose the moving system to be a rectangular coil of square cross-section. Then, very nearly, I_s will be proportional to the cross-section of this coil. Now conceive the cross-section of the coil, modified in such a way that the number of turns, and hence the sensibility, S_m, will increase, while the resistance of the winding is kept the same. Then R remaining constant, S_m will be some function of I_s. To find this function, we can reason as follows: If the cross-section of the wire is increased a times without a change in the number of turns, the cross-section of the coil is increased a times, and hence the moment of inertia is increased a times. But this increase in the size of the wire reduces the resistance to $\frac{1}{a}$ of its former value. Hence, to bring back the resistance to its original value, and keep the same size wire, the number of turns must be increased a times. This will increase S_m a times and again increase the cross-section a times. Thus altogether I_s is increased a^2 times. Therefore, we have by making these changes:

$$S_m \propto f(I_s) \propto \sqrt{I_s}$$

and

$$\frac{dS_m}{dI_s} \propto \frac{1}{2\sqrt{I_s}}$$

and putting these values in the general relation (17) found above, gives:

$$I_s = I_r. \tag{18}$$

This result means, that when we have chosen the moment of inertia of the winding of a rectangular coil, equal to the moment of inertia of the "dead parts," mirror or pointer, the resistance of the coil remaining always the same, we have designed the proportions of the coil such, that the galvanometer, in this respect, has the greatest figure of merit which it is possible to give it.

Every consideration shows us that in starting out to design a galvanometer, of any type which is to have a large number of D'Arsons, one should begin by carefully considering the selection of the mirror, pointer, or other contrivance essential to reading the deflections, so that this contrivance may have the least possible moment of inertia; for it is the mass of these

"dead parts" which ultimately sets a limit to the maximum figure of merit obtainable. The dispensing of "reading parts" in the Einthoven String Galvanometer is the essential reason for its enormous number of D'Arsons. Similar considerations hold for oscillographs, wattmeters, pointer volt and ammeters and other deflection instruments in which a high figure of merit is desired.

FLAT-COIL GALVANOMETERS.

The flat-coil galvanometer is a somewhat radical modification of the D'Arsonval type of moving-coil galvanometer. The modification was made by the writer to make the moving-coil instrument into a sensitive, substantial and portable galvanometer in which suspensions might replace the customary jewels. As will appear later, a suspended system may be arranged to withstand rougher handling than a system mounted in jewels, and there is the further marked advantage in a suspended instrument that there is nothing which corresponds to an initial pivot-friction. If very minute deflections of a pivot instrument are optically magnified, they will be found to be erratic and in no wise proportional to the forces acting. A suspended instrument, on the other hand, will deflect somewhat with the feeblest force and if its minute deflections are highly magnified by optical means, they will be found to be proportional to the deflecting force. This circumstance especially adapts a suspended instrument to zero measurements. Furthermore, the disk-like shape of the moving system lends itself in a portable instrument, with a suspended system, to a construction which requires a comparatively small height. Of several varieties of this type of instrument experimented with, the four-coil type has survived as being the best form and meeting in all respects the requirements demanded of it in a remarkably satisfactory manner.

Fig. 2 shows the construction of one type of this instrument, used as a pointer—portable instrument. The cut is made complete and explicit to save lengthy description.

It will be observed that when current energizes the four disk-like coils they all contribute to produce rotation in the same direction. A reversal of the direction of the current reverses the direction of rotation, the deflections, with equal current, being the same to either side of the zero.

At first sight this form of system might seem bad for giving a high figure of merit because so large a portion of the moving parts are far removed from the axis. While this is true, there are compensating advantages which practice shows makes the galvanometer very creditable in respect to figure of merit, while many features are secured which are of great practical worth. In the first place, as the galvanometer has no iron core there are only two air-gaps, one above and one below the coil, instead of four, as required by the D'Arsonval galvanometer with an iron core; in the second place *all* of the magnetic field is active

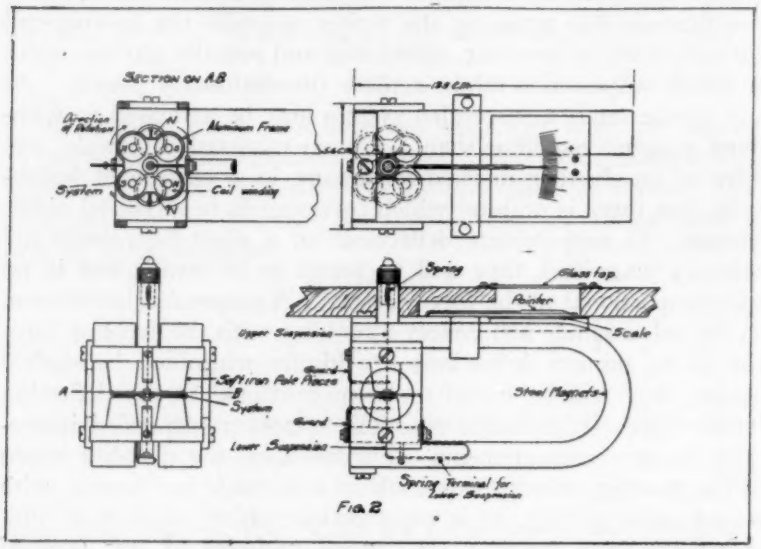


FIG. 2

at all times in producing a turning moment, regardless of the angular position of the system. In the D'Arsonval type, a magnetic field must be provided for the system to deflect into. This is shown by Fig. 3.

Thus if the coil section C_1 occupies one-fifth of the air gap, or space in which the coil turns, then four-fifths of the magnetic lines are at all times idle. Magnets of sufficient strength and capacity must be supplied to furnish five times as many magnetic lines as are at any one moment used. The four-coil galvanometer has a large advantage in this respect.

Thirdly, the aluminum form in which the four coils are

held serves admirably as a magnetic damper. Further, if the instrument is to serve as a ballistic galvanometer, its moment of inertia can be made very great out of material which is active in producing a turning moment and for such service the construction is ideal.

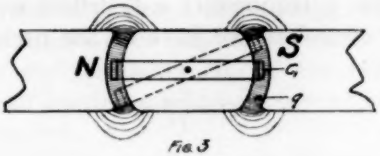
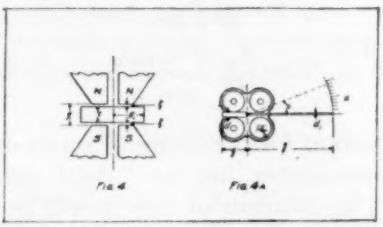


Fig. 3

The best proportioning of the system and coils to give specific results has received at the hands of the writer much thought and calculation. A few relations, which may have a general interest will now be given:



Reference is to be made to Fig. 4 for the significance of many of the symbols used. Let W = the diameter of the wire with which each of the four coils is wound; let q = the double thickness of the insulation on this wire.

Then the expression for the *number of turns* in the four coils is:

$$N = \frac{4rt}{W^2 + 2Wq}. \qquad (a)$$

The expression for the *resistance* of the four coils is:

$$R = \frac{16r^2t\rho}{(W^2 + 2Wq)^2} \qquad (b)$$

where ρ is the specific resistance of the wire.

The *torque* on the system due to a current i is:

$$t_1 \propto \frac{rti}{(t+p)\,(W^2 + 2Wq)}. \qquad (c)$$

If we give to the useful sensibility of the galvanometer, the definition of this quantity as explained on page 249, we assume that the system is supplied with a mirror, and that the scale is 1000 scale-divisions distant from the mirror. Then calling as above, S_m the sensibility, that is the number of scale-divisions which the galvanometer will deflect with one volt acting through one megohm, we have as the useful sensibility of the galvanometer:

$$U=\frac{S_m}{T^2}. \tag{d}$$

If the resistance of the windings of the four coils is R, we have for the figure of merit, of the galvanometer, expressed in D'Arsons,

$$F=\frac{U}{\sqrt{R}}=\frac{S_m}{T^2\sqrt{R}}. \tag{e}$$

Since
$$\sqrt{R}=\frac{4r}{W^2+2Wq}\sqrt{\rho t}$$

$$F=\frac{S_m}{T^2}\,\frac{W^2+2Wq}{4r\sqrt{\rho t}}, \tag{f}$$

which is one expression for the figure of merit of the galvanometer. If the galvanometer has no "dead parts," that is no mirror or pointer, its moment of inertia will be proportional to the thickness of its system, or:

$$T^2 \propto I \propto t \text{ hence:}$$

$$F \propto \frac{S_m(W^2+2Wq)}{4r\sqrt{\rho t^3}}, \tag{g}$$

but its sensibility will be proportional to the number of turns with which it is wound, and if we keep the size of the wire the same, $S_m \propto n \propto t$, hence:

$$F \propto \frac{W^2+2Wq}{4r\sqrt{\rho t}}. \tag{h}$$

This relation shows that, using a wire of given size, the figure of merit will continually increase as the system is reduced in thickness and as the radius of the coils is reduced (it being assumed that the radius, R_1, of the system as a whole diminishes in the same proportion as r). Thus, if the system did not have

to carry a mirror or a pointer, to gain in figure of merit it should be indefinitely reduced in size. Experiments confirm this conclusion, but in the case where the system must carry a pointer, we have to inquire what is the best length to give to the pointer (see Fig. 4).

Since in a given instrument any change which may be made in the length or mass of the pointer cannot effect the resistance of the coils or the sensibility, S_m, of the instrument, we can take the figure of merit as being inversely proportional to the square of the period. Or:

$$F \propto \frac{1}{T^2} \propto \frac{1}{I_t} \qquad (i)$$

where I_t is the total moment of inertia of the system and the pointer. Let a be the length of the arc over which the end of the pointer moves, and l the length of the pointer. If b is the constant angular deflection, $a = bl$.

The quantity which we wish to have as great as possible is not a, or F, but the product of a and F, or

$$P = Fa = Flb \propto \frac{l}{T^2} \propto \frac{l}{I_t}, \qquad (j)$$

is the quantity which, when the current is constant, is to be made a maximum. We see that this is so because, if we increase l for the sake of getting the end of the pointer to move over a longer arc, we do so at the expense of increased period, or smaller angular deflection in a given time, and hence, if the period is to be kept the same, the controlling force must be increased which would tend to diminish the arc. Or conversely, if l is diminished T would diminish and the angular deflection in a given time would increase, which would permit of using a weaker suspension thereby tending to increase the angular deflection and hence the arc. In other words, we want to make a galvanometer in which the end of its pointer shall move over as many scale divisions as possible while its useful sensibility or figure of merit is retained large as possible.

Now as before $I_t = I_s + I_r$, where I_s is the moment of inertia of the system and I_r is the moment of inertia of the pointer, together with that portion of the pointer y, which must be extended back of the axis for balancing.

It is easily shown, if $y=\frac{l}{4}$ in length, and if y and l are of uniform cross-section, and of respective diameters d and d_1, that the end y balances the end l when $\frac{d}{d_l}=\frac{l}{y}$.

If s = cross-section of long end of this balanced pointer and σ = the density of the material of which it is made, it can be shown that the moment of inertia, of the entire pointer, proportioned as above, about its centre of gravity is,

$$I_r=\frac{5s\sigma l^3}{12}, \text{ hence, as } P\propto\frac{l}{I_s+I_r} \text{ we derive } P\propto\frac{l}{2.4I_s+\sigma sl^3} \qquad (k)$$

and,

$$\frac{dp}{dl}=\frac{2.4I_s+\sigma sl^3-3\sigma sl^3}{(2.4I_s+\sigma sl^3)^2} \qquad (l)$$

This becomes a maximum when:

$$l=\sqrt[3]{\frac{1.2\ I_s}{\sigma s}}. \qquad (m)$$

In (m) we have a useful relation because the moment of inertia, I_s, of the system, can be obtained before the pointer is put on it, and the cross-section, S, and the density, σ, of the lightest material available for the pointer are also easily gotten. In a particular case the moving system of a four-coil galvanometer had a moment of inertia $I_s = 1.6$, the density of the material selected for the pointer was 3.3, and its cross-section was 0.0025 sq. cm. Hence, by the formula, the best length to make the pointer was found to be:

$$l=\sqrt{\frac{1.2\times1.6}{3.3\times0.0025}}=6.16 \text{ cm.}$$

In designing pointer instruments, such as galvanometers for use with thermocouples, etc., scant consideration is often given to this question: What is the most favorable length to give the pointer? but, that such consideration is important, must appear from the deductions given above. Accessory features, as magnets, suspensions, etc., are deserving of a few remarks.

For ease in shaping and in manufacture, cast-iron magnets are very suitable, and, if properly proportioned, they give a

field which is as strong as can be used with advantage in a galvanometer in which S_m is made large by the use of a weak suspension. There are always magnetic impurities in the coil system. The magnetic field in which the coil swings acts on these impurities, probably, in rough proportion to the square of the field strength. The result is, that the system takes on a polarity and tends, irrespective of the suspension, to set in a particular angular position. To show this strikingly, place the poles of a fairly strong permanent U-magnet near the poles of an ordinary wall form D'Arsonval galvanometer of about 400 megohms sensibility. It will generally show a permanent deflection of some 10 to 20 scale divisions as long as the U-magnet is held on.

The natural zero of the galvanometer is the position taken by the coil, which position is the resultant of the torsional force of the suspension, and the magnetic action of the field upon the magnetic impurities in the coil. When the field is weakened or changed in direction, the resultant controlling force changes, and hence a deflection results. In attempting an accurate measurement, by the Kelvin Double Bridge, of the resistance of a 3000 ampere standard low resistance, the writer recently used a Leeds & Northrup H-form Galvanometer in close proximity to one of the conductors carrying 1000 amperes. Whenever the circuit through the low resistance was closed the galvanometer deflected one scale division by the influence of the field external to the conductor. This deflection would have produced an error in measuring the resistance of one-tenth per cent., if it had not been discovered. The galvanometer was a very good one and the circumstance is related to show how precautions against exterior fields must be taken sometimes, even with moving-coil galvanometers. It also shows that little, if any improvement, can be obtained in weakly controlled galvanometers by using magnetic fields greater than can be obtained with cast-iron magnets. It may be mentioned here, also, that the chief cause of zero shift in sensitive D'Arsonval Galvanometers is due, not to the "set" in the suspension, but to a "magnetic set" which the coil takes when deflected in a strong field.

If a galvanometer is to have a quick period and a strong control, and be magnetically damped, then it is desirable to use a magnetic field of high intensity, such as can be secured only

by using soft Swedish iron pole-pieces and permanent steel magnets of the best quality.

Galvanometers which carry a pointer, or a mirror, and are intended for use on shipboard or for easy transportation and setting down without levelling, must be suspended between upper and lower suspensions, which are taut. Guards, which limit the movement of the system in all directions, together with a spiral spring in both upper and lower suspension, will effectually prevent the suspensions breaking, even when the galvanometer is subjected to severe jars.

It is desirable, however, to make the tensile strength of the suspensions great without undue increase in their torsional moment. The tension on the suspensions may then be made considerable and it becomes easy to accurately balance the system. This accurate balancing is essential to a steady zero and to make the system free from vibrations. A system, held between two taut suspensions, which is slightly unbalanced about its axis of rotation, is much more influenced by tremors than one which is carefully balanced.

The tensile strength of the suspension can be increased greatly without an increase in its torsional moment by making it of a number of round wires laid together in a cable, instead of a single wire. Thus:

Let $n =$ number of wires laid together,

Let $d =$ diameter of a single wire.

Then the torsion of one wire is, $t \propto d^4 \propto S^2$, where S is the cross-section of one wire. The total torsion of the n wires is:

$$T \propto d^4 n \propto nS^2.$$

If these n wires were to be combined into one, the tensile strength would remain the same, but the torsion would now be:

$$T_s \propto (nS)^2.$$

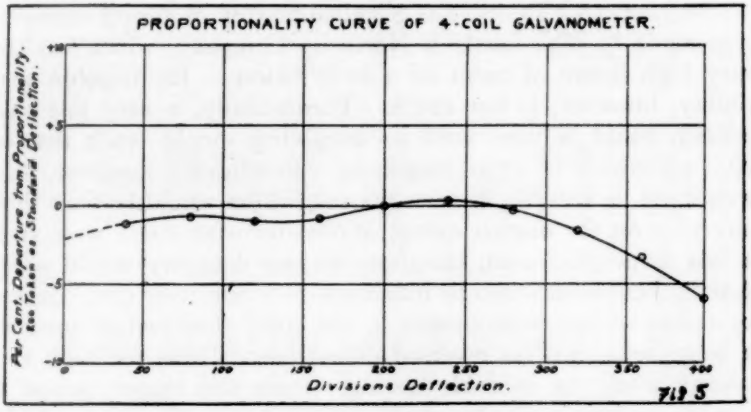
Hence,

$$\frac{T}{T_s} = \frac{nS^2}{n^2S^2} = \frac{1}{n}. \qquad (n)$$

This conclusion, that with equal tensile strength, the moment of torsion decreases with the number of strands into which a given cross-section of wire is subdivided, has great practical value. It is much employed in galvanometer constructions

where the galvanometers are to be made portable. Contrary to expectation, there is no slipping of one strand over the other in a manner to develop friction and uncertain return to zero. The same method has been applied by the writer, with much success, to supporting heavy systems upon a cable made up of very fine quartz fibres. Its more extended application is recommended.

The four-coil type galvanometer here described is admirably suited to a differential instrument, especially for use in temperature measurements with resistance thermometers. Its applications to this service have been pointed out by the writer in a former publication.[1]



When used as a deflection galvanometer, its deflections are not as proportional to the current flowing as might be desired. Fig. 5 is a curve which gives the average performance of the instrument in this respect.

The instrument has not been used with a mirror and fine suspensions for high sensibility work, but as it has been given a figure of merit of over 0.6 D'Arsons, it ought to serve well in this capacity.

In the present paper the discussion has been chiefly confined to galvanometers intended for use on constant or nearly constant current circuits. When galvanometers are designed for use with

[1] "Cooling Curves and a New Type of Apparatus for their Automatic Registration." Proc. of the Amer. Elec. Chem. Soc., May 7, 1909.

thermocouples and for reading millivolt or microvolt drops over low resistances, many points of design, and considerations regarding the galvanometer resistance, damping, etc., should receive attention; but the limits of this article will not permit a discussion of this phase of the subject. When dealing with galvanometers for use on constant potential circuits, it is preferable to use, as the expression for the figure of merit, the relation (12) given above. In this expression when $E_m = 1$ microvolt, $T = 1$ second, and $R = 1$ ohm; the figure of merit is unity, and then we might call the unit, a *microvolt D'Arson*.

We have collected together in a table the essential characteristics of sixteen different well known types of galvanometers for which see Table I.

Number 16 (Table I) is a galvanometer of the D'Arsonval type made by The Leeds & Northrup Company, which has the very high figure of merit of 2.80 D'Arsons. Its megohm sensibility, however, is but 121.8. Theoretically, a very fine suspension could be used until its sensibility should reach that of No. 13 which is 1750 megohms. Practically, however, this would not be feasible, because the suspension would be finer than any wire on the market except Wollaston wire. But were such a fine suspension used, the more serious difficulty would arise, that the coil would then be influenced to a relatively great degree by traces of magnetic matter in the coil. This would produce a large zero shift on reversed deflections. Thus, for high sensibility work, as in cable testing, where the longer period is not too serious a disadvantage, galvanometer No. 13 would be a much better instrument to use, although its figure of merit is but 11.4 per cent. of that of No. 16.

In respect to Table I the following remarks may be added. For the Einthoven String Galvanometer (No. 1) the resistance of the string was reduced to its copper equivalent, and a magnification of 100 was taken as the equivalent of a scale at 1000 scale divisions from a mirror.

The data for No. 2 was taken from Siemens & Halske's reprint No. 30, and the data for No. 4 was taken from an article by Dr. H. Sack in the same reprint. The data for No. 5 is from the Cambridge Instrument Co.'s catalogue. The data for No. 16, is based on the average of five instruments made by The Leeds & Northrup Company in August, 1910.

TABLE I.

No.	Type of instrument	Method of reading	Critical resistance for damping	Instrument resistance R	Megohm sensibility S_m	Complete period T	Figure of merit in D'Arsons $F=\frac{S_m}{\sqrt{R\,T^2}}$
*1	Einthoven String	Microscope, 100 Fold Magnification	Aperiodic	287	5.2	0.01	3000.00
*2	Dubois Rubens, Iron-clad Moving Magnet	Mirror	Aperiodic	290	12200.0	6.0	20.00
3	Siemens & Halske, High Sensibility	Mirror	120	200	2500.0	12.0	1.24
*4	Siemens & Halske, High Sensibility	Mirror		290	1220.0	6.0	2.00
*5	Ayrton-Mather	Mirror	Undamped	20	52.6	3.5	0.96
6	R. W. Paul, Single Pivot Milli-Voltmeter	Pointer	25	50	21.4	3.0	0.33
7	Weston, Voltmeter	Pointer	Aperiodic	75	0.25	0.5	0.115
8	Weston, Portable Galv.	Pointer	3000	280	13.8	1.5	0.37
9	L. & N., Type P	Mirror	140	124	85.0	8.5	0.10
10	L. & N., Marine Type	Mirror	Aperiodic	1660	21.4	2.0	0.131
11	L. & N., No. 2300 Standard Four Coil	Pointer	300	300	15.54	2.5	0.14
12	L. & N., Type H	Mirror	Aperiodic	544	295.0	7.0	0.26
13	L. & N., No. 2280 Wide Coil	Mirror	Aperiodic	1420	1750.0	12.0	0.32
14	L. & N., Steel Magnet	Pointer	500	230	8.8	1.3	0.344
15	L. & N., Special Small Four Coil	Mirror	500	85	6.4	1.0	0.695
16	L. & N., No. 2280 Narrow Coil	Mirror	200	180	121.8	1.8	2.80

* Data not obtained by author.

The Weston Voltmeter (No. 7) shows a figure of merit of 0.115 D'Arson. In considering the meaning of this low figure, it must be remembered that a light system has to carry a pointer which must be heavy enough to be perfectly rigid. The same system, fitted with a mirror would show a much higher figure of merit. The design of this instrument, as every one knows, is most scientifically worked out, and the fact that its figure of merit is low simply shows that one must exercise great caution against estimating the real worth of an instrument by this feature alone.

Philadelphia, Pa., August 16, 1910.

Polar Flattening of Jupiter's First Satellite. J. C. SOLA. (*Comptes rendus,* cl, 1224.)—Observed with powers of 550 to 750 on the 38 cm. Mailhat equatorial at the Fabra Observatory, the satellite Io presents a conspicuous flattening which is probably greater than that of any other known body in the solar system. From the measurements it appears that the equatorial plane of Io coincides with the plane of its orbit. The flattening was approximately determined as about 1 : 4.

Blast-Furnace Capacity in the United States. (*Iron Age,* lxxxvi, 8.)—From Nov. 1, 1907 to June 30, 1910, 35 blast-furnaces with a total annual capacity of 4,468,000 gross-tons were completed, and 12 furnaces, with a capacity of 287,000 tons dismantled. This shows a net increase in capacity of 4,181,000 tons. The impetus in this direction was, however, not exhausted for at that time 16 more furnaces, with a total annual capacity of 2,083,500 tons were in course of erection. The approximate capacity at the end of 1911 is placed at 40,228,000 tons. The highest level of consumption of pig-iron ever attained in the United States was during the latter part of 1909 and early in 1910, when it reached a level of 31,500,000 tons a year. This indicates to pig-iron consumers a comfortable margin of pig-iron capacity to meet the requirements of expanding trade.

Exportation of Agricultural Machinery. (*Iron Age,* lxxxvi, 8.)—During the fiscal year ending June 30, 1910, nearly 30 million dollars worth of machinery was exported, chiefly to Russia and Argentina. The competition is keen in Russia as Germany sold about $8,000,000 worth of farm machinery in that country, and England $5,000,000 worth. The value of the American machinery sent there is estimated at about $7,000,000.

FUZE-POWDER.

BY

COL. ANTON DOLLECZEK,

Former Director of the K. u. K. Powder Factory at Stein.

[Translated from the Zeit. für das Gesamte Schiess- und Sprengstoffwesen, v, 13, 14. By W. J. Williams, F.I.C.]

SINCE the idea first originated of delaying the explosion of a shell for a certain time after it had left the gun-muzzle, special powder compositions have been sought which would burn for a given time. This space of time is regulated according to the duration of the flight of the shell, and at its completion the bursting charge is ignited by the flash of the fuze. These powder compositions are compressed into convenient bulks, either in the form of columns (fuze-tubes), or of flat rings, or of spirals.

For this purpose the fuze may be lighted at a given point and ignite the charge at the end, as is generally done in ring fuzes; or it may be lighted at the beginning and be so regulated, according to the estimated duration of the flight, that the shell is exploded at the end. This regulation of the period of burning may be effected by cutting off the train, piercing it, or by pinching it in, or by its abstraction. This method was generally used in the earlier column trains and fuze-tubes. Combinations of the two methods are sometimes though seldom used; and quite recently the original method has been reverted to, of compounding different slow-burning, mealed fuze-powders for different shells, when there is a large variation in their periods of flight; and naturally in such cases the early methods are practised.

The use of a special, compressed, mealed fuze powder dates far back, notwithstanding that at that time the knowledge of ballistics and the efficiency of the artillery was very modest. In the famous book, "Vollkommene Buchsen-meister Kunst, etc." by the Royal Polish Lieutenant Master of Ordnance, Kazimier Siemenowics, published in 1672, in Latin, four different slow-burning compositions for fuzes were mentioned, *e.g.*:

No. 1. One part mealed powder, 1 part potassium nitrate, 1 part sulphur.

No. 2. Three parts mealed powder, 2 parts potassium nitrate, 1 part sulphur.

No. 3. Four parts mealed powder, 3 parts potassium nitrate, 2 parts sulphur.

No. 4. Four parts mealed powder, 4 parts potassium nitrate, 1 part sulphur, and also 3 parts of antimony.

The well-known book "Artilleriæ Regentior Praxis" by the K. u. K. Captain of Artillery, Michael Miethen, printed in 1682, also gives four fuze compositions:

No. 1. Three parts mealed powder, 2 parts potassium nitrate, 1 part sulphur.

No. 2. Four parts mealed powder, 2 parts potassium nitrate, 1 part sulphur.

No. 3. Six parts mealed powder, 3½ parts potassium nitrate, 2½ parts sulphur.

No. 4. Eight parts mealed powder, 4 parts potassium nitrate, 2 parts sulphur.

These four fuze-powder compositions, with some slight changes in the proportions, remained unaltered in Austria through the whole of the eighteenth and the first half of the nineteenth century, about which time very finely pulverized brick-dust was added to retard the time of burning; and two new fuze compositions were first adopted in the new edition of the "K. u. K. Feuerwerks-meisterei" (treatise on pyrotechny):

No. 1. Seventy-five parts potassium nitrate, 19¾ parts sulphur, 5¼ parts charcoal.

No. 2. Seventy-three and a half parts potassium nitrate, 22¼ parts sulphur, 4¼ parts charcoal.

A fuze-column 4 Viennese inches (10 cm.) long of No. 1 has a mean burning time of 22 seconds, and No. 2 of 30 seconds.

The regulations of the Prussian Artillery of the year 1860 show 8 different fuze compositions, which consist of mealed powder with various additions of potassium nitrate and sulphur.

Major Shrapnel, an Englishman (the reconstructor of the old device of grenades,—shrapnel,—which contained balls as well as a bursting charge and which are named after him), used fuzes of equal length but of different duration of burning; and the gun-commander of the Austrian Gun-cotton Artillery M.

1863, actually carried in his fuze-pouch 18 copper fuze-tubes, of equal length, but of different ranges, varying from one another by 100 paces, which were simply set in the fuze-seat of the shell before firing. These were painted in conspicuous colors for easy discrimination.

It is evident then that all the earlier shells prepared in the traditional way, had fuzes in columnar form (fuze-tubes), and a composition was used with a sectional burning period of about 20 seconds to 10 cm. of composition; since the time of flight, especially of howitzers and mortars, was comparatively long on account of the low initial velocity.

However, with the advent of rifled cannon and the more rational construction of shells and of powder, as the initial velocity increased and the range lengthened correspondingly, this composition was no longer satisfactory for shells loaded with small balls and intended to explode in the air (now generally called shrapnel). Wherefore, an especial percussion apparatus was brought into use for the ignition of the fuze, since the systems of breech-loading with the development of pressure on the shell excluded the ignition of the fuze by the powder charge. At this time black powder in the mealed form was generally used, without consideration as to whether the mealed powder consisted of crushed powder grains, or was compounded in special proportions.

The Austrian and Prussian shrapnel column fuzes for the Wahrendorf artillery system, consist of copper fuze-tubes rammed full of mealed powder paste; and at first were drilled out from the lower end to the requisite length for the purpose of timing them, but later were perforated by a fuze-punch at the distance corresponding to the time of flight.

Bormann was the first to use the horizontal position, *i.e.* perpendicular to the axis of the shell, for the fuze composition (mealed powder was still used), and this method of locating the fuze has become more or less the basis of all modern fuze construction. This—to designate it more simply—horizontal fuze is in a special disc-form, and it may be turned around the axis of the shell, to coincide with a piercer or pin on the fuze. An empirical scale is marked on the edge of the fuze-disc. If the beginning of the powder train in the fuze-disc is set so that it is marked with an O, or else with, for example, +, K. A., etc., or

the percussion-fuze chamber is directly connected by the fuze with the bursting charge of the shell, then the shell explodes more or less immediately after leaving the muzzle (action of canister shot). On the other hand, the greater the distance of the ignition point of the fuze is from where it burns through to the bursting charge, the longer the shrapnel flies through the air before it explodes. If the end of the fuze-ring (which is separated by a little bridge of metal from the beginning) is brought to rest over the specified orifice, the flight of the shrapnel has then reached its maximum. More or less, all time fuzes are constructed on this principle. In case the time fuze, for any reason whatever, does not explode the shell in the air, or when it is purposely cut out(as for example in practice), another contrivance is put in operation, which causes an explosion of the fuze by direct impact and thereby of the shell too, on reaching the target. Fuzes which combine the percussion function with the time function are called " double fuzes " and are now general.

As long as a shrapnel range of 2000 to 3000 paces was satisfactory, ordinary powder sufficed for the fuze-ring. But soon higher demands were made both for accuracy and effect. The original intervals of the fuze-ring, which were about one second, were narrowed down to half a second and an eighth of a second; and definite explosion intervals and explosion heights were striven for (so the ordinates of the points of explosion might be termed in relation to the lineal distance of the target) and the uniformity of the combustion of the powder train extended—termed " Fuse-slowing " (literally " spreading ").

The powder maker, of course, is only interested in the fuze-slowing, and it was considered, in Austria at any rate, that grain powder is preferable to the mealed powder, favored up to this time. This assumption has much in its favor, since as a rule the mealed powder is not so thoroughly incorporated, if it is not made from grain-powder; and, moreover, experience teaches that the uniformity in burning of the powder increases with the size of the grains, though within narrow limits and within small periods of time.

Table I shows the results of experiments made in the K. u. K. Powder Factory at Stein, carried out with spherical, slightly graphited powder, of the composition potassium nitrate 75 per

cent., sulphur 10 per cent., and 15 per cent. of alder-wood charcoal, containing about 74 per cent. of carbon.

By the "size of grains" is meant the mesh of the upper and lower sieves.

The time of combustion is the mean of 10 fuzes in a double fuze, where both discs together are 21.1 cm. long with a diameter of 2.5 to 3.0 mm. and a depth of 4.0 mm.

As the size of the grains increases from 0.20 mm. up, the time of combustion increases from about one-half to one second, and soon becomes constant, whilst the variation in burning remains practically uniform. The density decreases as the size of the grain increases, and it might be assumed that the greater the density the less the time of combustion would be.

TABLE I.

Size of Grains within the limits of mm.	Density	Time of combustion, in Seconds	Moisture, per cent.	Variation in burning, in Seconds
0.10–0.20	1.67	18.50	0.9	0.68
0.20–0.40	1.65	18.87	0.9	0.62
0.40–0.60	1.60	19.92	0.9	0.64
0.60–0.80	1.59	20.01	0.9	0.60
0.80–1.00	1.57	19.92	0.9	0.47
1.00–1.20	1.53	20.20	0.9	0.60
1.20–1.40	1.48	20.48	0.9	0.68

But this is not so; extended experiments in this direction apparently prove the contrary; for they show in each case that the cardinal virtue of a good compressed mealed powder, with a uniform combustion, is the small variation in burning.

Table II shows this difference with three experimental powders each of two different densities. It shows that the time of combustion increases with the density, but the variation in burning decreases, yet the difference is not significant. Hence it is established in the Austrian Regulations (specifications) that very high densities, at least as high as 1.8, should be attained.

These are measured by Holecek's volumeter (pycnometer) and the size of the grains is fixed at from 0.30 to 0.65 mm.

The gigantic advance in weapons, extending from the present speed of fire to the hitherto unapproachable range of the guns,

allows the artillery expert no rest, compelling improvement in guns and projectiles. Amongst the many methods, some completed and some only attempted, to attain this end, only two need to be taken into consideration by the powder maker:

1. The extension of the range of shrapnel over 2000 paces.

2. The introduction of automatic time-graduators or apparatus with a similar object.

As to 1, the increase of the shrapnel range depends chiefly on the length of the period of combustion of the time fuze. This can be accomplished in two ways, namely, with a *longer* powder column made of the same powder as that generally used; or with an ordinary powder column (ring) with a *slower burning*

TABLE II.

Kind of powder	Density of powder	Mean time of combustion, Seconds	Maximum variation in burning, Seconds
Compressed fuze-powder M 97	1.847	17.64	0.30
	1.475	16.58	0.66
Compressed fuze-powder No. 93	1.870	24.94	0.18
	1.806	23.50	0.73
Compressed fuze-powder No. 93	1.908	24.06	0.44
	1.728	23.43	0.54

fuze-powder. It is well known, and proven by experiment, that the irregularity of the combustion,—the variation in combustion.—increases with a slower burning fuze. In general, artillerymen have chosen the first method of increasing the range of shrapnel and almost all modern field-pieces have their powder columns (rings) so lengthened that they (especially in the larger calibres) have two, three and often four superimposed fuze-discs, and these are permitted to burn away successively. Occasionally a special additional fuze, or supplemental fuze, is added to the built-up fuzes already mounted on the shell. The shrapnel range to point of burst is thereby carried over 5000 paces; the actual range is doubled.

It is obvious that this method, with which the fuze maker is particularly concerned, has its limits, and cannot be continued

until the successively superimposed fuze-discs equal half the weight of the shell. It is expensive, too, since the cost of the fuze alone is greater than that of the unregulated shell. Lastly it is not proved that a fuze of the generally-used powder burns better than a better constructed, carefully made, but slower burning fuze made of a special powder. The many ignitions and transferences of ignition, the various sectional and oblique piercings of the disc-fuzes, are, once for all, the greatest sources of error in the construction of fuzes; moreover, the variation in burning will always increase with the greater length of fuze.

However, simple black powder cannot be used, since all compositions of a similar kind will only give 18 to 21 seconds' duration of combustion for about 20 cm. of fuze.

Black grain powder in the proportions which should theoretically give a perfect decomposition of the separate ingredients, viz., 74.81 per cent. potassium nitrate, 13.33 per cent. sulphur and 11.86 per cent. charcoal, has a duration of combustion of 18.35 seconds and a variation of 0.41 seconds.

Powders of similar composition give similar results in different countries. The English "Time and Percussion Fuze No. 60" has, under the above circumstances, a period of combustion of 20 seconds for a 20 cm. fuze and can be set up to 5670 metres. The Italian double fuze, M. 1900, burns just as long and up to 5600 metres, while the Italian mountain guns are fitted with a fuze burning 21.4 seconds. The Russian aluminum fuze, of the types 1900, 1901, 1902 and 1903, has a double fuze-channel covering 22.8 cm., and burns for 22 seconds (or 20 cm. burn for 19.3 seconds) and is timed for 130 Saschenen. The extreme subdivision of 1/10 * Saschenen, about 40 metres, marks the permissible variation in burning. This fuze is of excellent construction, and one of the best that is used in any army. Holland too has an aluminum fuze timed up to 5600 paces, and Servia one for 5000 paces, made by Schneider & Creuzot. Among German fuzes, the so-called Richter fuzes, the field shrapnel fuzes C/70 and C/72, have a minimum period of combustion of 15.8 seconds and a maximum of 28 seconds. The earlier single stage shrapnel fuzes filled with compressed powder, sometimes with

* Sic. in original, but as 1 Saschen = 7 ft., the figures are obviously erroneous. [Trans.]

mealed powder, burned for 9½ to 10½ seconds, just as long as the upper disc alone now burns.

It is evident from the above mentioned details, that almost all artillery have a special fuze-powder, which has approximately the same proportions as black powder; but, of course, this powder is not always satisfactory for special cases. For example, the shells of the high-angle-fire guns require slower burning fuzes on account of their slower flight. The United States of America alone uses the old mealed powder in its service combination-fuze, which is compressed into two fuze-discs with a total length of 18 cm. and a pressure of 480 kilograms per square cm. In Austria they have different fuze-powders with burning periods of 14 to 30 seconds in the double fuze M 93.

The question now arises whether it would not be simpler and more practical to give up the complicated and expensive building up of the three and four stage fuze-discs and return to the old method, and establish a slower burning fuze-powder, that would burn just as evenly as the compressed powder hitherto used. If the demands of the general staff upon the producer of shrapnel go much farther, they will compel him to this solution.

As to 2, the introduction of automatic time graduators would make the production of fuze-powders so difficult and complicated, as to become a game of chess (lottery). The reason is that with a slow-burning powder, and with the present fuzes which can scarcely be made any longer, the time subdivisions on the outer rim would be so minute that it would be impossible to avoid mistakes, even from a bad light, and this introduces a new source of error. It might perhaps be possible, since the subdivisions are so difficultly legible, to place them in two series, one over and one under a dividing line, so that whole divisions and halves should be above and the quarters and hundredths below. But that is outside the limits of this article. (Nonius.)

Such are the demands made by a slow burning fuze such as has been described, and how are they to be combatted?

1. It must burn as evenly as possible, *i.e.*, the greatest variations in burning of one group or series must be very small, or the difference of the period of burning between the longest and shortest burning fuzes, should be a minimum. This minimum is naturally dependent on the duration of the time of burning, and

must be deduced rationally from that; at the greatest it should only be one-fortieth or one-fiftieth of the fuze's total time of combustion when at rest.

2. The time of burning of a given length of fuze, must be sufficiently slow to correspond with the shrapnel's time of flight for a range of 6000 to 8000 paces. This can be attained by a fuze-length of 35 to 40 seconds' duration of combustion.

There results from these considerations,—taking the extreme range as 8000 paces,—a fuze-powder which requires about 40 seconds to burn away, when at rest, in a fuze-channel about 20 cm. long; and the variation in burning should not exceed one second at the highest for complete combustion. Since at such a long range the end velocity of the shell has dropped about 200 metres, the fuze-length should cover about 100 metres more, which is very little at such distances.

Now follows the cardinal question,—How can such a slow-burning, compressed fuze-powder be produced? There are two ways of doing it.

a. Changing the proportions—in which may be included the addition of such bodies as increase the fuze-powder's period of combustion without affecting its combustibility.

b. A decrease in the carbon-content of the charcoal used, which in fact is nothing else than an addition of wood-meal (partially burned charcoal) to normal powder.

AS TO *a*.

So far as concerns the proportions it has been previously shown that the mixture of potassium nitrate, sulphur and charcoal which makes the best propellant powder, when used as a burning (combustible) powder only burns for 18.35 seconds, with a variation of 0.41 seconds. None of the black powder burns over 23 seconds, and by mere abstract change of proportions it is not possible to increase the time of combustion more than 10 seconds with the best possible efforts of the manufacturer. In these experiments the customary decayed black alder-wood charcoal was used, containing about 72 per cent. of carbon. The experiments were carried out with six different mixtures, with the conditions as similar as possible, in order to study the influence of the potassium nitrate and the carbon.

So far as the influence of the sulphur is concerned, Table III,

varying only in the increased time of combustion, shows that an excess of sulphur, over 15 per cent., with the potassium nitrate practically constant and very little carbon, acts as a retardant; without, however, attaining the desired time of combustion (40 seconds) or the desired uniformity; except in the first and last experiment, where the variation was only 1/44 and 1/45 of the time of combustion.

TABLE III.

Experimental powder				Attained	
Percentage of mix			Density	Time of combustion, Seconds	Variation of combustion, Seconds
Potassium nitrate	Sulphur	Charcoal			
59	37.0	4.0	1.854	33.82	0.76
75	19.0	6.0	1.877	30.11	1.11
73	22.0	5.0	1.828	29.63	1.48
76	17.0	7.0	1.836	29.00	1.27
77	15.5	7.5	1.854	28.29	1.17
67	27.0	6.0	1.825	26.52	0.58

Moreover, with short periods of combustion, sulphur has no particular influence and gives no results when added within the limits of 2 to 15 per cent. Hence only the potassium nitrate and the charcoal act as retardants or accelerators. And actually within the limits of 70 per cent. to 80 per cent. for potassium nitrate, and 20 per cent. and 10 per cent. for charcoal an increase of the time of combustion is perceptible, with a minimum of about 13 seconds; and with 80 per cent. potassium nitrate, 10 per cent. sulphur and 10 per cent. charcoal, its maximum reaches 25 seconds.

The above refers to a decayed black alder-wood charcoal, burnt black, containing about 72 per cent. carbon; the same quality of white alder-wood charcoal gives a fuze burning 4 to 5 seconds slower, but also a somewhat greater variation in burning. The desired end, a fuze-powder burning for 40 seconds, cannot be attained by method *a*, merely by a change of proportions.

Moreover, the action of different admixtures does not recommend itself practically, although it is interesting to follow their

influence on the period of combustion and the variation in combustion, which is often difficult to comprehend. Those will be mentioned here with which experiments have been made in the K. u. K. Powder Factory.

Graphite.—The most important is graphite, which is added to quick-match powders to increase their time of burning in certain percentages—in private (mercantile) factories up to 6 per cent. In small percentages this addition is hardly noticeable, yet the variation in burning is considerably less. It would almost appear as if the single, very finely divided, particles of graphite distribute themselves uniformly and regularly between the ingredients of the powder, and thereby arrest the accumulation of gas, and the increase of pressure, and so induce a more uniform combustion. Practically this agrees with the quick-match powder, the regular combustion of which shows comparatively very small variations as compared with fuze-powders, in spite of its less careful preparation and only one hour's mixing in the incorporating mills.

Graphiting.—The graphiting of a fuze-powder until glazed is, however, not to be recommended. (Graphiting is covering the powder grains with an extremely fine layer of graphite with a view to its better preservation.) A graphited powder can be pressed into a fuze-ring (channel) just as well as another, but the intimate incorporation of the separate powder grains to a compact fuze-train is not as perfect as might be wished. The small cavities in the fuze-train show this by their pitting, which is visible to the naked eye when a graphited powder is compressed.

Barium Nitrate.—At the K. u. K. Powder Factory the whole or partial replacement of the formerly exclusively used potassium nitrate by barium nitrate was tried. With barium nitrate alone in the normal proportion, the experiment gave a negative result, in so far that the fuze-ring could not be ignited; by replacing one-third [*sic*, query ¼?] of the potassium nitrate by barium nitrate, so that the proportions were potassium nitrate 57, barium nitrate 19, sulphur 6, and decayed black alder-wood charcoal 18 parts, the fuze burned 23.49 seconds and 39.09 seconds; in the first case the black alder-wood charcoal contained 72 per cent. carbon, and in the second case only 62 per cent. The variation of burning was 0.74 in the one case and 0.30 seconds in the other, 1/32 and 1/30 [sic. query 1/32 and 1/130?] of the

period of burning, thus it was still somewhat too large; but this experiment gave us something to think about.

In France and Belgium also they had attempted, at the suggestion of Captain Wynant, to replace 40 per cent., even 80 per cent., of the potassium nitrate by barium nitrate, by which they hoped to attain a less brisant (explosive) but more impulsive (propellant) force. This was obtained, but the solid residue was too great.

Steatite (Soapstone) and Brick-dust.—When these substances are added in small amounts, and in a finely divided condition to the powder, they do prolong the time of burning, but not in the same way as graphite. However, they fill the fuze-ring with ash, and thus diminish the apertures for the gases and finally smother the fire. Their use is only to be recommended with caution, and they have not given satisfaction at the K. u. K. Powder Factory in the experiments undertaken by the order of the K. u. K. Technical Military Committee.

In the old "Military Chemistry" by Captain Gottlieb Scherrer, it is stated that one-half of the powder burned in a gun-barrel is converted into gas, whilst the other half remains as a solid residue; later statements say that two-thirds of the original weight remain as solid residue. [Débus says about 56–58 per cent., Trans.] This is not important for fuze-powder, but only how much fuze is burned from the fuze-ring, and how much ash is left in the fuze-ring, and in what condition it is left. To ascertain this, many hundreds of fuzes, filled with the most diverse powders and then burned, were carefully weighed before and after burning—naturally only the fuzes under consideration.

The average weight of the compressed powder in the upper and lower fuze-discs before burning was 25.635 Gm. Weight of the residue in the fuze-channels, weighed immediately after burning,—12.614 Gm. The powder converted into gas then weighed 13.021 Gm.,—about one-half. The largest residue (14.509 Gm.) was obtained from an experimental powder which contained potassium nitrate, sulphur, and decayed black alder charcoal in the proportions 67:27:6. The smallest residue (11.50 Gm.) was yielded by an experimental powder with almost normal proportions (74:10:16).

It follows from these significant experiments that in spite of all there is not much to fear from choking the fuze-channel with

residues, and that there are several ways of diminishing the danger. Actually the daily weather conditions have considerable influence on the choking; if the weather is damp, the residue is softer and more easily expelled than in hot weather.

Vaseline.—Of those additions to fuze-powder which leave no residue, there are still to be mentioned the fatty oils, which the Swedish Major Unge, the well-known constructor of air-torpedoes, used as an addition to his propellant, though really only to prevent erosion.

In the K. u. K. Powder Factory from 1 per cent. to 4 per cent. of vaseline, liquefied by heat, was added to the powder during its manufacture, once in the pan of the incorporating mill, and another time during glazing, without any effect being noticeable. Moreover how this affects the ash deposit of this fuze-powder was not investigated at this time.

Compressed Gas-forming Substances.—There still remains the choice of one addition, which can possibly further the slow combustion of the fuze, without disturbing the uniformity of burning, and without increasing the residue. This is by the intermixture of those substances which consist only, or chiefly, of gas-producing ingredients, and by their combustion are decomposed into gaseous products, *e.g.*, sugar, alcohol, etc.; and the idea is aroused of compressing gaseous products into the fuze mixture and fixing them there in some way. So far experiments of this kind have not been made at the K. u. K. Powder Factory, and nothing regarding them is to be found in literature.

AS TO *b*.

The Influence of Different Well-burned Charcoals.—In the first place every wood for making charcoal for powder is of a different value in its action on the period of combustion, not only in respect to the place where it grew and the age at which it was cut; but furthermore the texture and the chemical properties of the different kinds of wood suitable for powder-making, change the period of combustion of the fuze-powder, even when they are so burned as to have the same content of carbon.

In the experiments at the Factory the following were considered: decayed black alder-wood, hazel, willow, white alder, poplar, and cork. The first two were apparently equal, and so

were willow and white alder; yet with the same content of carbon, the latter gave 4 to 5 seconds greater time of combustion and burned somewhat less uniformly. Poplar charcoal, burning somewhat slower, was excluded from the later experiments, because it frequently ignited in the ovens, though nominally better burned charcoal.

The behavior of the cork charcoal was peculiar, so that experiments with it would certainly have been continued, if there had been a possibility of burning the masses of cork (which were difficult to handle) to the proper degree in the present primitive plant. This was done as well as possible, and cork charcoal produced, which showed the mean carbon content of a retort to be about 42, 49, 52, 59, 62 and 72 per cent. But actually each charge of charcoal produced, was a mixture of more or less

TABLE IV.

	Period of combustion, Seconds	Variation in combustion, Seconds
Sample No. 1.....	31.44	0.73 (1/43 of the time)
Sample No. 2.....	39.37	0.90 (1/43 of the time)
Sample No. 3.....	41.17	1.02 (1/43 of the time)
Sample No. 4.....	47.49	1.12 (1/40 2f the time)*
Sample No. 5.....	57.75	1.54 (1/42 of the time)*

* *Sic.* No. 4 should be 1/42; and No. 5 should be 1/38.

" burned to death " cork, and of cork not burned at all, with the most diverse gradations of charring; and in spite of this, results were obtained as good as the best, with high periods of combustion.

A complete fuze-powder was made from the above-mentioned cork charcoal, in the proportions 75 parts of potassium nitrate, 10 parts sulphur, and 15 parts charcoal, and burned as usual in the fuzes M 93 a.

With the exception of the over-burned charcoal, which showed very great irregularity in combustion, the period of combustion of the rest was as shown in Table IV.

It cannot be doubted that, if a uniform burning of the charcoal is desired, with rationally burned cork the actual variation in burning may be considerably decreased, within not too exacting limits. Furthermore, powder made of cork charcoal can be

unusually finely pulverized, mixes very intimately with the other ingredients, and can be easily compressed to a very high density; a density of 1.828 can be attained with cork-charcoal powder without trouble, at which density with other kinds of powder, the plates bend and fissures appear. Without any special procedure, the K. u. K. Powder Factory obtained an average moisture of 0.25 to 0.30 per cent. (that of other kinds of powder was 0.8 to 1.0 per cent.), and this powder, in the experiments carried on by the order of the K. u. K. Technical Military Committee, suffered no loss of its dryness and stability (good qualities) after two years in a damp magazine, while other powders, placed there at the same time, were almost unserviceable.

However, with the use of cork charcoal a *slow and uniformly burning fuze-powder* could not be produced; before that can be done better apparatus for coking (charcoal making) must be placed at the disposal of the powder manufacturer. A rationally working steam coke-oven seems the most suitable.

This end can be attained by various well-burned charcoals from decayed black alder-wood or white alder-wood, but even in this case a rationally constructed coking oven is necessary. Hitherto the proper value has never been placed on the use of different well-burned charcoals for black powder, as strictly speaking, only black and brown (red) charcoals are mentioned, without specifying their percentage of carbon. This neglect may have been of small consequence for a propellant powder, but becomes of importance when a fuze-powder is in question. It has been shown here that 1 per cent. of carbon affects the time of burning in the fuzes M 93 a to the extent of about one second.

Extensive experiments were made at the K. u. K. Powder Factory at Stein with alder-wood charcoal,—more particularly with decayed black alder-wood—in which the latter (with a carbon content varying from 27 per cent. to 80 per cent.) was always added to the mass in the same proportion of 15 parts to 75 parts potassium nitrate and 10 parts sulphur.

The results of several hundred experiments are submitted in the graphic form in Chart I. The curve of the time of combustion is shown by the ordinates; the base line, in which the percentage yield of charcoal is shown at equal intervals, is theoretically a curve similar to a parabola, in which the vertex expresses an approximate time of combustion of 15.5 seconds.

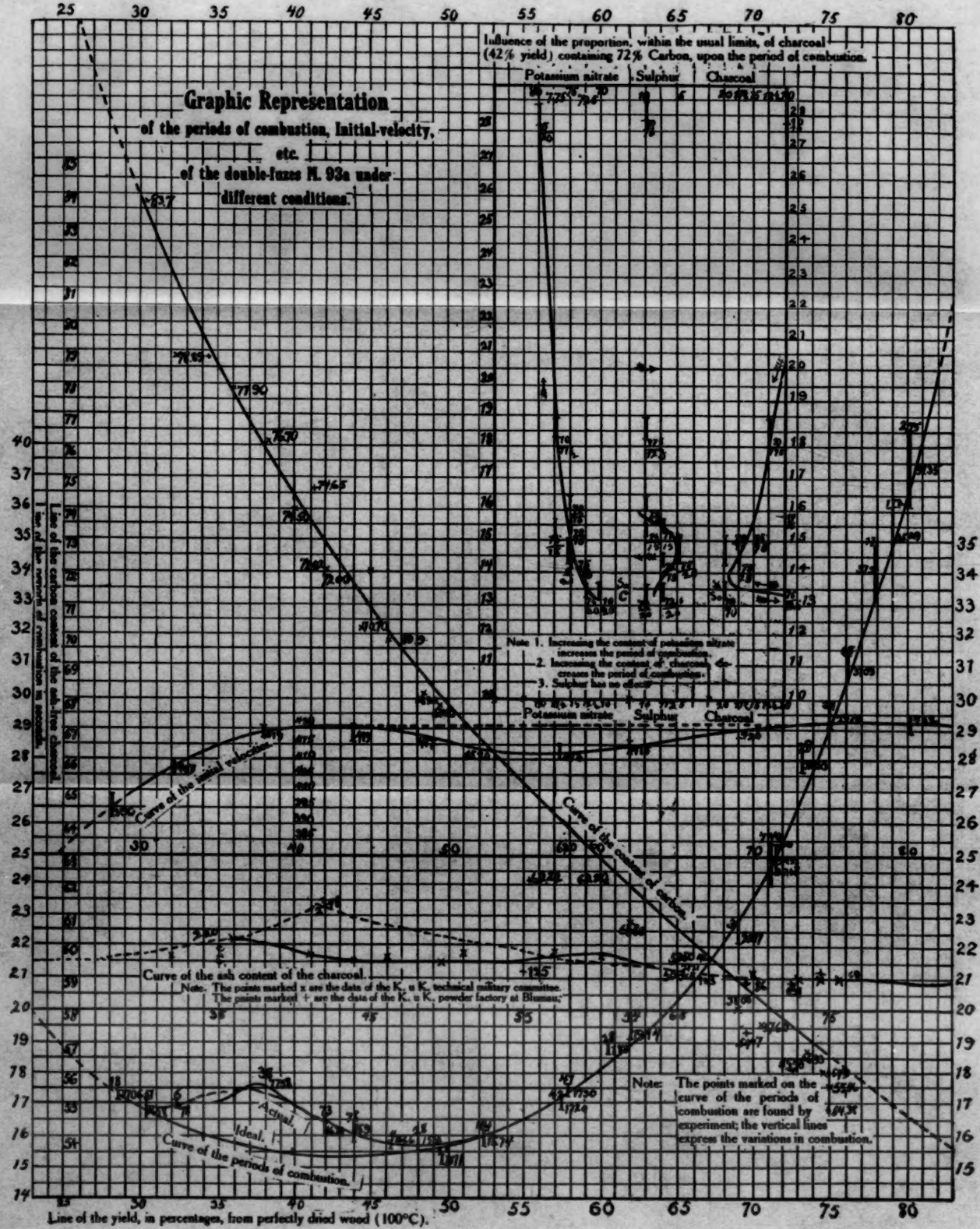
(A shorter time of combustion is not attainable with the above proportions.) Here the decayed black alder-wood gave a yield of 42 per cent. with 71.95 per cent. of carbon. In both the parabolic curves the times of combustion increase as much as the variations in combustion; and from Chart I it has been attempted to reach a longer time of combustion of 37.35 seconds, with a remarkable variation of 2.75 seconds (1/14 of the whole time) with the above-named proportions. This was attained with a very highly burned charcoal (80 per cent. yield and the very low carbon content of 53.85 per cent.). A more complete burning of the charcoal than a 27 per cent. yield (about 86 per cent. carbon content) can only be carried out in platinum retorts, otherwise it is hopeless.

This desired end may also be attained by more complete burning of the charcoal when further premises, to be investigated later, are worked out.

In fact the curve of the periods of combustion is not a parabola, but at about 67 per cent. carbon content it turns aside towards the higher ordinates, again reaches a maximum (at 76 per cent. carbon content) of 17.58 seconds period of combustion, and from there on falls again.

It is easy to assign the reason for this phenomenon (a parabola with the vertex depressed). At the time when about 67 per cent. of the decayed black alder-wood in the retort has become charcoal, the distillation of tar becomes very active, and the fluid tar-products boil, become solid and then burn to ashes. The ashes, and to some extent the unburned tar, collect in the interstices (pores) of the charcoal itself, and make it burn irregularly; it is for this reason that the periods of combustion of a fuze-powder, which is made from decayed black alder-wood containing 67 to 76 per cent. carbon, differ so much. As a matter of fact the curve on Chart I expressing the ash content, shows a not insignificant elevation exactly at the place where the depression of the vertex of the parabola expressing the periods of combustion, commences. This thesis will be still better confirmed later on by experiments on charcoal-making carried out with greater care and more exact analyses of the charcoal for powder. In this case there stood at the disposal of the K. u. K. Powder Factory in addition to their own laboratory, that of the Technical Military Committee and that of the Blumau Powder Works, yet

CHART I.


Graphic Representation
of the periods of combustion, Initial-velocity, etc.
of the double-fuzes H. 93a under different conditions.
Influence of the proportion, within the usual limits, of charcoal (42% yield) containing 72% Carbon, upon the period of combustion.
Potassium nitrate
Sulphur
Charcoal
Note 1. Increasing the content of potassium nitrate increases the period of combustion.
2. Increasing the content of charcoal decreases the period of combustion.
3. Sulphur has no effect.
Curve of the initial velocities.
Curve of the contents of carbon.
Curve of the ash content of the charcoal.
Note. The points marked x are the data of the K. u K. technical military committee.
The points marked + are the data of the K. u K. powder factory at Blumau.
Actual.
Ideal.
Curve of the periods of combustion.
Note: The points marked on the curve of the periods of combustion are found by experiment; the vertical lines express the variations in combustion.
Line of the yield, in percentages, from perfectly dried wood (100°C).

it appears from the curve of the ash content that all three statements differ from one another. One curve, inclined in a flat bow, cutting the period of combustion curve, expresses the carbon content of the decayed black alder-wood charcoal, also referred to in the base-line.

The conversion into charcoal of the decayed black alder-wood was just as difficult as that of the cork, and all the hindrances encountered there were also met with in this case. As far as these primitive means would allow, the law of the combustion of a fuze-powder, made from decayed black alder-wood, is shown by the data of the chart. All further burnings and investigation of fuze-powder, undertaken at the powder factory, and those pertaining to the production of decayed black alder-wood charcoal, were carried out on the basis of this chart and controlled by it. A better apparatus for charcoal making would only serve to make the data of the chart more accurate. The factory directorate has proposed the apparatus of Violette le Duc to the K. u. K. War Ministry of the Empire.

A further support of the assumption that still longer periods of combustion and smaller variations can be attained with charcoal burned systematically and in a manner free from objections, is the following circumstance:

The powder factory, in the course of its investigations, obtained possession of several hundred kilogrammes of the *brown prismatic* powder M 82 (for which at that time there was no use), because this powder, made by a celebrated firm, contained a very carefully made, high grade charcoal (52 per cent. carbon content). Used by itself as a fuze-powder this was not ignitible; but when mixed with black powder in certain proportions and thoroughly worked up, it gave periods of combustion of 40.21, 33.63, and 26.54 seconds, with variations of 1.12 seconds (1/36), 0.7 seconds (1/48) and 6.18 seconds (1/135 of the total time). [NOTE.—6.18 sec. or 1/135 is evidently a misprint. Trans.]

From the foregoing illustration the possibility is presented of making a very slow-burning fuze-powder without using cork charcoal; yet in my opinion powder made with cork charcoal should give better results.

The question now arises how such a slow-burning fuze-powder can be produced. Practically the method is as follows:

Ingredients of the Powder.—The best double-refined potassium nitrate. Pure refined sulphur. For long periods of combustion barium nitrate is substituted for one-third [really one-fourth. Trans.] of the potassium nitrate. For charcoal, apart from cork charcoal, decayed black alder-wood should be used, or for longer periods of combustion, white alder-wood; and according to the requirements these should be burned to a carbon content of between 50 per cent. and 70 per cent. Finally there is no harm in adding 1 per cent. to 2 per cent. of the finest graphite and *1 per cent. of hot vaseline.*

Proportions.—The normal proportions 75 : 10 : 15 are understood. Graphite and vaseline are added at the expense of the charcoal and sulphur. To increase the period of combustion ("slow" the powder) potassium nitrate is added, and the charcoal decreased; but that makes ignition more difficult. Sulphur changes nothing within the above-mentioned limits.

Pulverizing.—Well-burned charcoal, on account of its hardness, is first ground between millstones and then pulverized with small balls for about 2 hours alone, and then from 4 to 6 hours with the sulphur. The pulverization of the charcoal is the most difficult, and at the same time the most critical part of the whole production of fuze-powder.

Preliminary Mixing.—The preliminary mixing of a fuze-powder in mixing barrels with the aid of lignum-vitæ balls must be strongly disapproved, because a large number of the very finest splinters are split off the sides of the barrel and off the wooden balls and greatly contaminate the fuze. Instead of the preliminary mixing, customary with other powders, an hour's mixing with shovels in lots of 100 kilogrammes is recommended.

Incorporation.—The fuze-powder is incorporated for a longer or shorter time according to the season, but never less than 6 hours, so as to obtain an intimate incorporation and sufficient heat to soften the sulphur, as it binds better with the other ingredients in this condition, and helps the fabrication of the powder. (If vaseline is to be mixed in, this is best done in the incorporating mill.) To prevent dusting, 4 to 5 liters of water, —preferably warm rainwater,—are poured into the incorporating pan at short intervals.

Breaking-down (Corning).—According to the old custom, thus I name the conversion of the cakes which are very hard

and very adherent when they leave the incorporating mill, and which have very varying densities, into a coarse-grained but uniform powder.

For fuze-powder the lower sieves of the Le Feber granulating machine, in which the breaking-down takes place, should have a mesh not greater than 1 mm. at the most, for then the broken-down material can pass directly to the press, omitting the operation of after-mixing. The sides of the breaking-down machine, the corning-balls, all new tools and implements must be carefully inspected for any splintering of the wood.

Pressing.—The broken-down material, dried to 1.5 per cent. moisture (green powder), is pressed in an hydraulic press with the usual precautions. It is preferable to use small press plates (such as carry about 6 kg. rather than those usually used which carry 10 kg.) and only a few of them, and the pressure must be raised, until a density of at least 1.8, according to Holecek's Volumeter, is reached. This corresponds to from 300 to 500 atmospheres.

The most suitable size for grains from the cylinder graining machine is between 0.30 and 0.65 mm.

Glazing for 95 hours.

Whatever may be done in the way of *investigation and research* on fuze-powder, the present custom of burning fuzes charged with this powder first when at rest, and then of firing shrapnel furnished with such fuzes from guns, should decidedly be condemned; for in this way new sources of error appear, which may lie in the fuze (its construction, manufacture or adjustment) or in weather conditions, but are ascribed, altogether too readily, to the fuze-powder.

The investigation of fuze-powder should be limited to the *period of combustion, the uniformity of combustion* (difference of burning), and to the *ignitibility* of the powder; and this should be done under similar weather conditions, in a locality with a constant temperature. Experiments as to its range are independent of these matters. Then with a powder found to be suitable, as possessing certain constant factors, further experiments can be undertaken on the ignition and on the firing range; and all inaccurate functioning can be ascribed to varying conditions.

The simpler and more primitive these appliances for testing fuze-powder are, so much the better will they attain their object.

Simple steel shells, similar in shape to the old Bormann or Breithaupt shrapnel shells; simple tubes of a compressible metal, which are filled at a given pressure and cut off at a given length; or even calibrated tubes of a given length, which are pressed full of powder; these will always suffice if they are made alike and if their period of combustion,—from the ignition at one end until the fire breaks out at the other end,—is measured by an accurate chronometer. The arithmetical mean of the periods of combustion gives the required period; the difference between the longest and shortest period gives the maximum variation in burning; and the ease of ignition of the compressed powder is measured by a mechanism which causes an ordinary hammer to function. In this way undefined sources of error are avoided as much as possible, each day's production of powder is tested at a remarkably small cost, and only those powders found to be uniform are accepted and then blended. The result must be satisfactory.

Fuze Construction.—Although not strictly within the limits of this article, the modifications and constructions of shrapnel fuzes, which follow from the above-mentioned changes in the fuze-powder, must not be overlooked; for it is a *sine qua non* that the powder-maker and the fuze constructor must work hand-in-hand. A fuze with a slow-burning powder needed only a single ring, but with a somewhat larger burning surface, for previously existing ranges. As advances were made towards increased ranges for shrapnel, then simply a second ring sufficed, and consequently the many ignitions and transmissions of ignition, which are admittedly one of the chief causes of variations in burning, especially in fuze M 93 a, were avoided and eliminated.

Further it must be borne in mind that with a slow-burning powder the combustion must be facilitated; which means that the effect of the ash deposited in its course must be indirectly surmounted. This can be done by such a construction of the powder ring (channel), that at the beginning it is made broader and deeper, to give room for the passage of the back-streaming flame, and thus to neutralize the effect of the deposit of ash.

Thirdly, it is advisable to provide for a free air current, in addition to that which results from the flight—a single escape vent appears to be decidedly too small, or more vents should be provided.

Fourthly, the slow-burning fuze naturally demands a stronger *initial-ignition*. This principle was first established by the researches of the K. u. K. Technical Military Committee, since several fuzes were rejected by them as unignitable, which ignited without delay at the powder factory; so a remedy was grasped at, and the beginning of the powder column of such a fuze was supplied with a quicker burning mixture. Particularly the powder containing graphite was treated in that manner, which seemed best to suit that powder.

The old method of assuring the *retention and transmission of fire* by a complicated arrangement of quick-matches has fortunately been dropped and replaced by cylinders of compressed powder. But in order to offer still fewer sources of error, the orifices through which the fire is propagated should be filled with the finest grained powder. At any rate the elimination of quick-matches, and their replacement by loosely poured in powder, which is held in place by tin foil, seems to best meet the requirements, according to the investigations of the K. u. K. Powder Factory.

True Melting Points of Metals. M. VON PIRANI (*Ber. Phys. Ges.*, cccx, 48.)—The equivalent in black-body temperatures of metal surfaces is ascertained by optical pyrometry. To obtain the true temperature, Pirani uses the electrical resistance as an intermediate check, since this is not affected by surface conditions. The chief work was done on tungsten and tantalum. Taking the melting point of platinum as 1788° C., that of tantalum is 3100° and tungsten 335° C.

Ferro-Molybdenum Made by the Thermit Process. (*Eng. and Min. Jrnal.*, xc, 6.)—Ferro-molybdenum is now produced by the Thermit process and is coming into general use as a valuable alloy in high grade steels. Until lately pure molybdenum only was produced by this process, but to supply a demand, ferro-molybdenum is now being manufactured. The advantage of ferro-molybdenum over metallic molybdenum is that it does not oxidize, and that it can be more easily alloyed with steel, owing to its lower melting-point.

Tensile Strength of Aluminum Zinc Alloys. W. D. BANCROFT. (*Mech. Eng.*, xxv, 329.)—The alloys were made by melting 99.9 per cent. pure aluminum with "Bertha Pure Zinc" which had

less than 0.2 per cent. of impurities. When a thermocouple introduced in the melt indicated that the temperature had fallen to 50° C. above the freezing point, as indicated on Shepherd's diagram, the alloy was cast into an ice-cooled graphite mould, and quenched in ice-water immediately after solidification. Test pieces prepared in this way showed very high tensile strengths (25,000 to 35,000 lbs. per sq. in.). The 60 per cent. aluminum alloy having the maximum tensile strength of about 41,000 lbs. per sq. inch. The ductility of these alloys is very low, on 3-in. lengths below 5 per cent. elongation, but was considerably increased by annealing, with a corresponding diminution in the tenacity.

Action of Hydrogen on Carbon Monoxide. A. GAUTIER. (*Comptes rend.*, cl, 1564.)—When a mixture of hydrogen and carbon monoxide in the proportion $CO+3\ H_2$ is passed through a heated porcelain tube the CO is reduced, even at 400° C. The production of steam attains a maximum at 1220° C. The maximum amount of carbon dioxide is found at 900°C. In most cases no carbon is deposited, but methane is produced. Further experiments of heating CO with steam at 550° to 800°C produced formaldehyde. The author applies these results to explain the composition of volcanic gasses.

Estimation of Radium. S. J. LLOYD. (*Jour. Phys. Chem.*, xiv, 476.)—Radium is estimated by the emanation produced in a solution of the radium salt in a known time. The effect of the presence of various reagents and precipitates in the solution of the radium salt is also investigated. For the accurate determination of radium by this method the presence of HCl or HNO_3 is necessary. If $BaSO_4$ or $BaSO_3$ is present in the solution, prolonged boiling or repeated determinations are requisite. In the case of freshly precipitated $BaSO_4$ the retention of the emanation is mechanical only, due to the entanglement of radium chloride or sulphate within the fine precipitate, the effect of heat being to release the radium and permit the removal of the emanation.

A New Resistance Furnace. F. A. J. FITZGERALD. (*Metallurg. and Chem. Eng.*, viii, 317.)—In this furnace the charge in the crucible is heated by radiation from resistance; in some forms it may be described as a furnace with a sealed reaction or heating chamber. Zinc has been experimentally produced in this type of furnace; and the efficiency of these furnaces has been determined at about 78 per cent. It is pointed out that in certain forms of electric furnace, the loss of electrically generated heat can be nearly eliminated by surrounding it with an envelope of burning gas. Experiments on large furnaces have shown that this arrangement is very economical.

AVIATION AND AEROPLANE MOTORS.

BY

HENRI PETIT,

Ancien élève de l'Ecole Polytechnique.

(Translated for the JOURNAL from *La Nature.*)

[The development of aerial navigation, almost unknown but five years ago, has with the adequate demonstration of its possibility and ultimate practicability proceeded with most rapid strides. In the account here presented, originally contributed to *La Nature,* of the requirements of the *fin de siecle* heavier-than-air machine, the author analyzes in detail the essential features of the power plant equipment and suggests a probable solution of the problems of future development.]

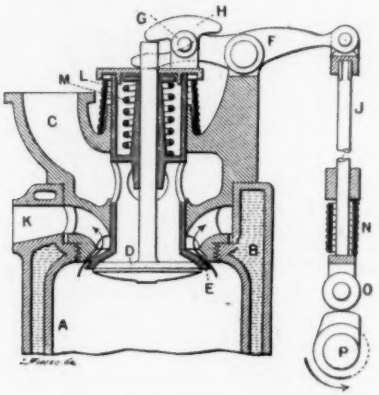
IT has been said, and with reason, that the automobile alone made aviation possible; in fact it is the light and powerful petroleum motor employed in this vehicle that has given wings to mechanical birds.

One is tempted to assume that a very light motor is still indispensable to aviation. Progress made in the past two years is such that designs have, or at least *should have,* reached permanent types. The light motor is no longer a necessity. The recent exploit of Sommer who carried three passengers, that is, a useful load in the neighborhood of 450 lbs., is sufficient proof of this. The motor could evidently have weighed considerably more and the apparatus still have been capable of carrying the operator and one passenger. Does this mean that light motors are to be discarded and all efforts toward securing lightness abandoned? We entertain no such thought.

The light motor which made possible the flights with early apparatus will now make flight more certain and nearly free from danger. It is only too well known that all failures of the motor result in an immediate and often rapid descent which at times may be exceedingly dangerous. Notice also that the prominent aviators who undertake a cross-country flight select their course with care and mantain a very high altitude. Lambert, who ordinarily does not seek high altitudes, in soaring over Paris, was obliged to ascend to a height of more than 1600 feet.

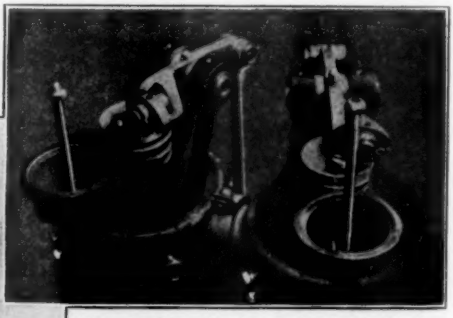
In lightening the motor it may prove possible (and that is probably the future solution) to equip the apparatus with

FIG. 1



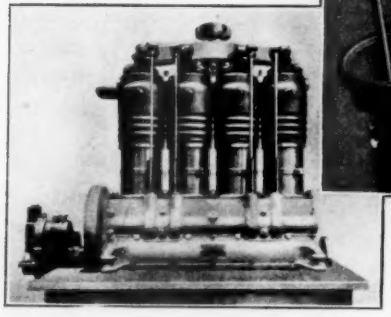
Panhard and Levassor concentric inlet and exhaust valves operated by a single cam.

FIG. 3.



Exterior view of valve mechanism in head.

FIG. 2.

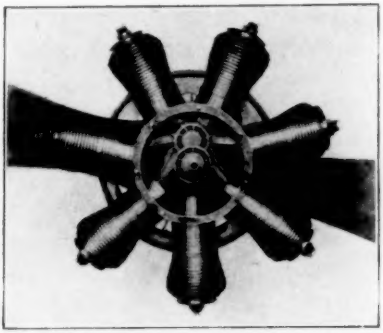


Exterior view of Panhard-Lavassor 4-cylinder motor. Weight without cooling water, 210 lbs.; 35–45 horsepower.

two motors each capable of insuring the motion of the aeroplane. In normal flight the two motors would be attached to the propeller through a double clutch, each operating at only half its normal

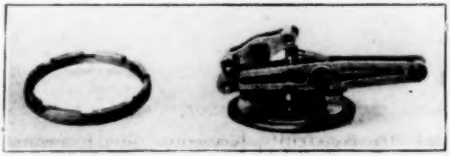
power. Should one of them fail the operator uncouples it, while the other driving with full power permits the flight to be continued until a favorable landing is reached. The low efficiency of two motors operating at half power will doubtless provoke criticism. It is known that the efficiency of an explosive motor diminishes somewhat rapidly when it operates at a power too far below normal. But less primitive methods than those found on existing engines may be employed for controlling the speed.

FIG. 4*a*.



One connecting-rod of the Gnome motor is integral with the head, the six others are pointed to the head.

FIG. 4*b*.



Exhaust-valve levers of Gnome motor.

Speed control by varying the lift of the exhaust valves for example, long in use on the De Dion motors, gives excellent results from the point of view of efficiency.

FUEL CONSUMPTION.—Fuel consumption has to-day acquired an importance little suspected but two years ago. Present-day flights are no longer measured in minutes; the hour has been exceeded by many pilots and it is reasonably safe to predict that the day is not far distant when the aeroplane will enter the field of touring. Notwithstanding all precautions, landing being

always a precarious matter, it becomes essential to avoid as far as possible the necessity to replenish the fuel supply during a trip. As the allowable weight of combustible is limited, a motor of high efficiency will become essential. A few figures will serve to emphasize this requirement.

A petrol motor consumes about 1.05 pints of fuel per horsepower hour. Let us consider an aeroplane, whose motor is developing 29.6 horsepower, moving with a mean speed of 37.3 miles per hour, an average performance of actual apparatus. The hourly consumption will be 32 pints, that is, 53 pints per 60 miles. Adding to this about 8.4 pints of lubricating oil, and we shall still be below actual results. Sustained flights by aeroplanes may

FIG. 4c.

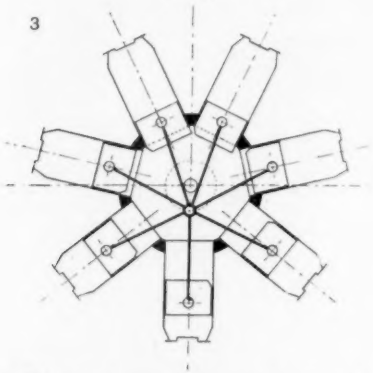


Diagram of connection in Gnome motor.

be regarded as the highest achievement in transportation. It is safe to expect that the aviator will aim to make a trip, for example, of 180 miles without stopping. He will require 95 pints of petrol and 25 pints of lubricating oil, weighing together, with their recipients, about 132 lbs., or nearly the weight of a passenger!

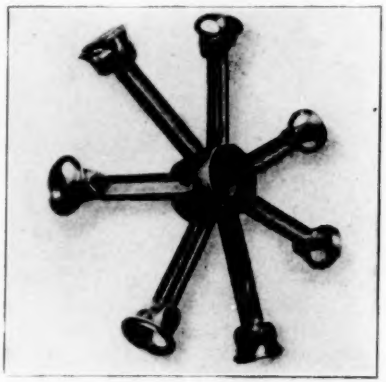
Notice, however, that fuel consumption in the majority of motors is appreciably greater; greater, it may possibly be said, in inverse ratio to the amount of study they have received with a view to securing extreme lightness. Thus according to the assertion of one manufacturer an early extra-light motor consumed 3.2 pints per horsepower hour. This motor, moreover, weighed scarcely more than 3.3 pounds per horsepower. A 49

horsepower motor, consequently, developing only 30 horsepower in normal flight would weigh 165 pounds and would require for a journey of 180 miles a supply of 285 pints of petrol and at least 42 pints of lubricating oil weighing, all told with tanks, about 308 pounds. The total weight of motor + petrol + oil thus reaches 470 pounds.

The motor whose fuel consumption was referred to above weighs but from 5.5 to 6.6 pounds per horsepower, that is, 330 pounds. The total weight in this case reaches 460 pounds. From a simple comparison of figures, the conclusion is obvious.

THE LIGHT MOTOR.—Be it as it may, it is interesting to investigate how a reduction in weight of a motor may be

FIG. 4*d*.



The seven connecting-rods of the Gnome motor.

effected. We shall consider this question in what follows. Three distinct methods are available:

1. Reduction in weight of each component member.

2. By better design, the elimination of a certain number of parts.

3. By increasing the power without increasing the ratio of weight to power.

Let us investigate in the above order each of the three methods.

1. REDUCING WEIGHT OF PARTS.—The obstacles here are that the strength must remain unimpaired in reducing the weight and that the number of parts available is limited.

Cylinders.—The cylinders which in automobile motors are

almost always of cast-iron may be materially lightened if made of steel, which having greater tensile strength can be much thinner. Moreover, with cast-iron cylinders it is necessary to provide additional thickness to cover defects in the foundry. By separating the cylinder from its water-jacket and by placing the valves in the head, both the exterior and interior may be entirely finished on a lathe.

As to the permissible thickness, it is possible to reduce this to the dimension required by calculation of the stress on the material. However, in water-cooled cylinders the thickness should be sufficient to prevent a too rapid dissipation of the heat of the explosive gases and consequent considerable loss in efficiency. The plan of placing the valves in the head, on the contrary, favors high efficiency, the explosion chamber having thus a minimum of wall surface. With a view to keeping all parts of the cylinder an

FIG. 4e.

Master connecting-rod and piston of Gnome motor.

uninterrupted double curved surface of revolution the two valves have by some makers (R. E. P., Panhard, Pipe) been arranged concentrically with the axis of the cylinder.

The water-jacket can be made of copper or aluminum, crimped and brazed to the cylinder. No small difficulty has been experienced in making a durable joint with the cylinder, the difference in expansion of the two materials causing frequent leaks. It seems, however, that the results obtained by crimping followed by silver brazing, or even by a galvanic deposit, are durable and practical. Formerly the cylinders of certain motors were made partly of steel and partly of aluminum, but that construction is no longer employed.

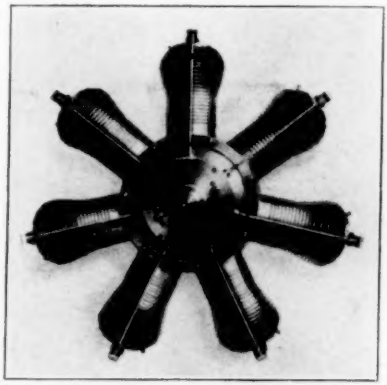
The Piston.—The piston may receive the same treatment as the cylinders to secure lightness, that is, cast-iron may be replaced by steel or even aluminum. The gain in lightness here is rela-

tively small but it permits of a high rotative speed, which, as will be presently seen, increases the power per unit of mass.

Frame.—The housing can be considerably lightened by the adoption of a special arrangement of cylinders. It is thus, in the rotative *Gnome* motor, reduced to its ultimate simplicity.

Fly-Wheel.—It is not difficult to save in weight on the fly-wheel, without reducing its moment of inertia. For this, it has sufficed to concentrate its mass at its periphery and to increase its diameter. In the motor, Dutheil and Chalmers, for example, it consists of a rim of steel connected to the hub by steel spokes as in a bicycle wheel.

FIG. 4*f*.



Exterior view of Gnome motor.

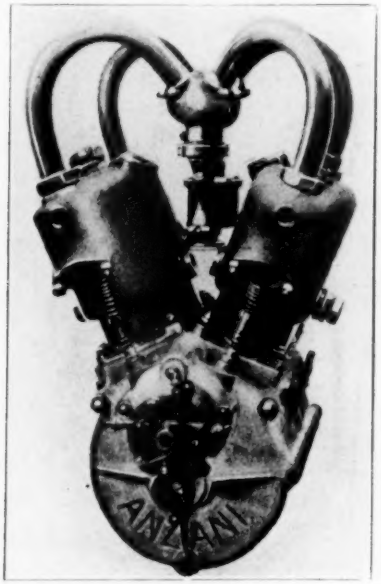
Accessories; Radiator.—The cooling system has been the object of many attempts towards simplification. Many designers, adopting air-cooling, eliminate it almost entirely. It is reduced, in that case, at most, to a fan which forces the air through a brass jacket embracing the cylinders. In the rotative Gnome motors the displacement of air by the cylinders insures an adequate cooling effect.

In water-cooled motors the radiator with its supply of liquid constitutes a considerable weight. It has been greatly reduced, first by the construction of special extra light radiators, which arranged either under the wings (Santos-Dumont) or on the body (Antoinette) of the aeroplane, then in reducing to a minimum the quantity of water. Thus, in the Antoinette apparatus,

the radiator is intended not to cool the water but to condense the steam which escapes from the cylinder-jacket.

The above comprise nearly all the reductions in weight that one may hope to effect on the component parts of the motor. Connecting-rods, valves, and cones have been pared down by automobile motor designers to the limit of lightness. As they say in shop argot they cannot be *skinned* any further.

FIG. 5.



Four-cylinder Anzani V-motor.

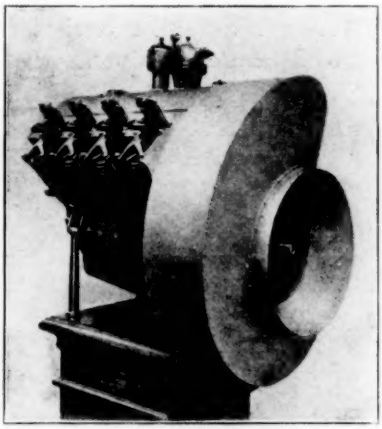
2. ELIMINATION OF CERTAIN MEMBERS.—The automobile motor as we understand it carries no superfluous members. Each has a determinate function and if a single one of them is removed the mechanism stops. To accomplish a lightening by the method of elimination, the separate members of the motor must be so correlated that one of them can fulfil the functions previously distributed among several others. Along this line of attack beset with obstacles little progress has been made.

Non-essential Accessories.—First, those accessories that are not absolutely essential have been suppressed, such as the muffler

and exhaust piping. Even the carburetor has disappeared in some motors and with it the admission piping (Antoinette, Wright). In these the fuel is injected directly over the valves.

It is not alone, however, the craze for extreme lightness that has prompted the designers of these two motors in this radical suppression. The carburetor is at present an object of attack from numerous critics who are even disposed to treat it as a scapegoat. It is, nevertheless, a question whether its defects are as serious as its critics would have us believe.

FIG. 6.



Renault aviation motor.

Fly-Wheel.—The fly-wheel, already lightened in some motors, has been entirely omitted in many others. It is understood that its function is to regulate the action of an explosive motor whose torque is very variable, the more so as the motor is equipped with a smaller number of cylinders. On motors with six cylinders the fly-wheel ceases to be theoretically necessary, the torque is in effect always positive and never falls to zero. *A fortiori* with eight cylinders it may be entirely dispensed with though it is still, shall we say, wisely provided on a few motors of this class. The omission of the fly-wheel is not unattended by disadvantages. While apparently suppressed, the propeller keyed to the crank-shaft replaces it and absorbs the shocks due to variable and sudden torque of the motor.

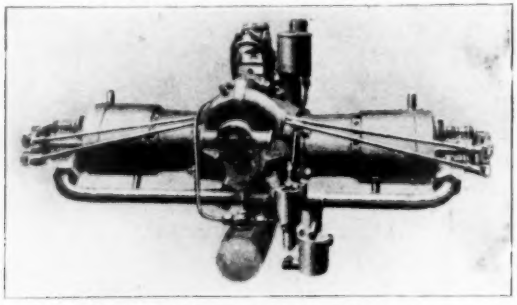
A better solution is embodied in the rotative motors (Gnome,

Burlat). In these motors it is the mass of the cylinders which revolve and, consequently, replace the fly-wheel. There is here no omission but purely and simply the replacement of one member by another without interfering with the proper functions of the latter.

Crank-Shaft.—While the crank-shaft has not been entirely suppressed, it has been reduced to next to nothing in rotative motors. All the connecting rods are attached to one or at most two crank-pins. Whence a reduction in weight of the crank-shaft as well as the connecting rod heads which frequently merge into one.

Cams and Valves.—M. Esnault-Pelterie has not considered negligible the weight of cams and valves. In his seven-cylinder

FIG. 7.



Dutheil-Chalmers double opposed motor.

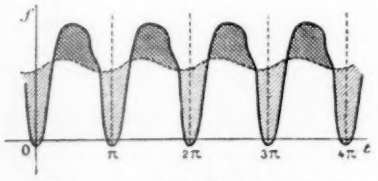
motor a single cam controls the entire distribution. The concentric valves are lightened and so arranged that their cooling is a simple matter.

3. INCREASE OF THE RATIO OF POWER TO WEIGHT.—The increase of power per unit of mass is far from being a new problem. The designers of the racing cars intended to compete for the Gordon-Bennett cup, when a maximum weight was specified, have exhausted the subject and there remains little to be done for aviation motors.

High power per unit of mass is allied in many ways with good efficiency. In other ways it is entirely independent of efficiency. A discriminating choice among these contradictory conclusions is needful to produce a motor of high unit power and of high efficiency.

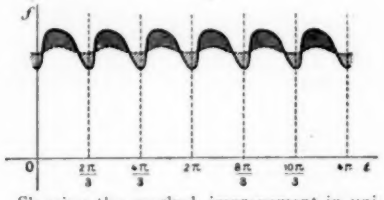
Without entering into a discussion of all the data of the question we shall be content to announce the conclusions. The form of what is known as the characteristic curve of an explosive motor is familiar; it expresses the power of the motor as a function of its angular velocity (Fig. 10). Clearly the power first increases with the speed, reaches a maximum, then decreases rapidly with any increase of speed. The velocity Ω corresponding to the maximum power, P, is known as the critical speed. It is conceivable that the further towards the right the position of the

FIG. 8.



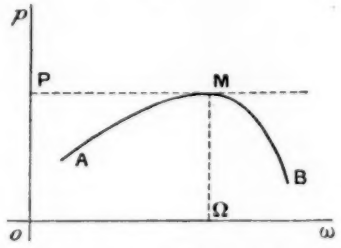
Full curve, tangential effort; dotted curve, tangential resistance.

FIG. 9.



Showing the marked improvement in uniformity of torque over that of a 4-cylinder motor.

FIG. 10.



Characteristic curve of explosion motor. Abscissæ, angular velocity; ordinates, power.

maximum point, M, assumes, the greater will its value become. Hence the search will be made in other terms to find the high-velocity motor.

Satisfactory efficiency requires high piston speed; hence, at the same time, high angular velocity and a long stroke. Lengthening the stroke increases the weight without much gain in power. Let us also inquire, on this point, into the lessened efficiency. Nearly all aviation motors are *square*, that is, bore equal to the stroke. High compression increases the efficiency and also the

unit power. Nevertheless it does not appear that in this direction the question has been fully investigated for aviation motors. The maximum of compression 90 to 100 pounds per square inch, which with care can be attained with petrol, is far from having been reached. This is due, without doubt, to the difficulty of cooling a high-compression motor when employed for aviation.

The ruling temperature in aviation motors, which is as high as possible, while again favorable to efficiency, is offset by an excessive consumption of lubricating oil. In this, as in all things, a happy medium should be observed.

In conclusion, the light motor will be a high-speed motor, the compression will be moderate. The cylinders will be of steel with vanes or a separate water-jacket. It will be equipped with at least six cylinders, generally seven, to avoid the use of a fly-wheel.

In a future article we shall study the practical realization of those conditions among various designers and a classification of their motors.

Thulium. C. JAMES. (*Amer. Chem. Soc. Journ.*, xxxii, 517). About 250 Gm. of the bromate of Cleve's thulium were obtained by the continued fractionation of those rare earth bromates more soluble than erbium bromate. Thulium salts are of a pale bluish-green color, which is readily changed by minute amounts of erbium, the solution becoming first yellowish-green, then yellow, colorless, and finally pink with the increase of the proportion of erbium. The author is determining the atomic weight of the metal and is continuing the fractionation to ascertain if more than one element is present.

Course of Radio-active Projections. L. WERTENSTEIN. (*Comptes rendus*, cl, 869.)—It is known that α-particles are propagated in a practically straight line to the point where they stop, each kind of α-particles having a well-defined path. The author has investigated the case of the projection of RaB by RaA in order to ascertain whether the projection exhibits an analogous character. The results show that the RaB particles traverse a definite path equal to 2 mm. at 45 mm. pressure, and that the length of this path is inversely proportional to the pressure, the product of path and pressure being about 90. At the normal pressure the path is about 0.1 mm. corresponding with a penetrability 400 times less than that of the α-rays of RaA.

AERIAL PROPELLERS AND SOME TEST RESULTS.

BY

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AND

ROBERT OLIPHANT BOSWALL, B.Sc.

(Slightly abridged from London *Engineering.*)

[The helical propeller, be it hydraulic or aerial, acting as it does upon a yielding and unconstrained medium, is a device offering exceptional difficulty of analysis from strictly theoretic consideration as is well known. Marine engineers have therefore resorted to the more direct method of experiment to secure the requisite data on the subject. This paper is an account of the application of the same process to aerial propellers, the results of which can scarcely fail to prove of value in selecting an aerial propeller.]

1. AIRSHIP stability and safety will be found to be very largely dependent on an exceptionally high translational speed, which will necessarily reduce the risk of flight due to prevailing or sudden air currents to a minimum.

2. The best propeller for a given aeroplane, the propeller shaft of which rotates at the highest economical speed for the particular engine mechanism, is that propeller which produces maximum translational speed per brake horsepower or, in other words, that propeller which gives the greatest thrust per brake horsepower.

Hence it follows that in the design, construction and testing of propellers, we must have regard to:

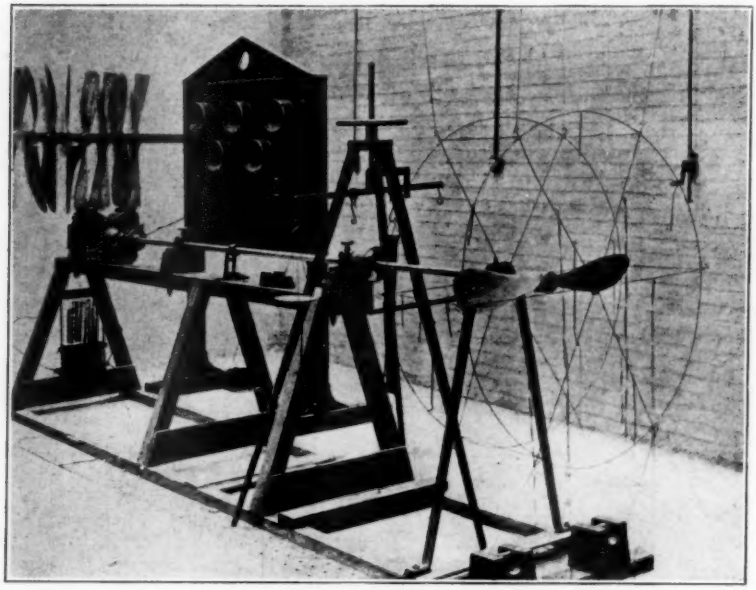
1. The rotational speed of the propeller.
2. The total thrust and the thrust per brake horsepower.
3. The aerial or translational speed of the propeller.

With respect to the design and construction of aerial propellers, it is perhaps too great to expect, in the present state of our knowledge, that any theory elaborated can do more at the present time than indicate forms of propellers to be constructed with a view to the experimental determination of their

relative values. In fact, it is not too much to state that, in the first instance, any results of value will have to be obtained from the experimental side of the problem, propellers being designed, constructed and tested and unsuitable forms eliminated on the test results.

The question then arises as to which is the best experimental

FIG. 1.



Apparatus for testing aerial propeller.

method of attack in testing propellers for aerial use. Three methods suggest themselves:

1. The static test method.
2. The whirling table method.
3. Testing under conditions of aerial flight.

The first two methods only have been attempted as far as the authors are aware; and while the third method is undoubtedly the ideal one, the difficulties have apparently prevented its being resorted to.

Nevertheless the difficulties are not so great as would appear at first sight; the practical solution of the problem being chiefly

a financial question. What is wanted, provided the necessary funds are available, is an experimental track for combined aeroplane and propeller-testing similar to that previously suggested by the authors. Such a track for the testing of aeroplanes, engines, and propellers under conditions approximating, in many respects, to actual flight has in the authors' opinion become an urgent necessity. Even from a financial stand-point the difficulties are not insuperable.

During the winter session 1909–10 provision had to be made for the laboratory work for students taking the aeronautical classes being held in the Mechanical Engineering Depart-

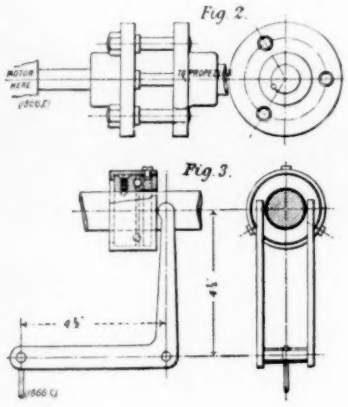


Fig. 2.

Fig. 3.

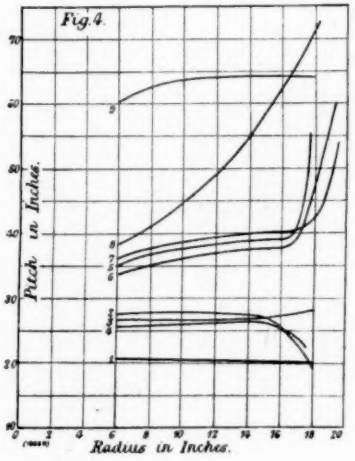


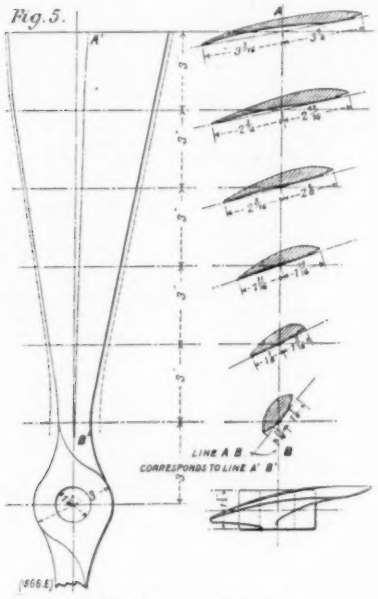
Fig. 4.

ment at the Northampton Institute, Clerkenwell, E. C., and among other experimental work carried out with the assistance of the students and staff was a series of tests on aerial propeller models with the object of obtaining definite information and comparative results for differently shaped models. In all twelve propellers were tested and the chief particulars for nine propellers and the results derived from the tests are given in the following pages.

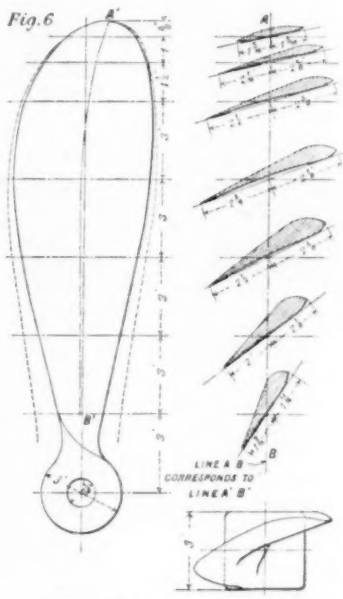
Testing Apparatus.—The important question of floor-space available made it impossible at the time to consider any other apparatus than for the static tests which, although not giving the means for determining actual thrust and horsepower under

what may be termed "ideal conditions"—that is to say, conditions attaching to actual flight which can only be obtained by the use of apparatus of the whirling table or continuous track type necessitating a large ground area—yet enables a student to compare results given by different forms of blade surface and to arrive at some definite conclusions as to their relative values as a means of propulsion.

The apparatus used is illustrated in Figs. 1 to 3. In its construction the apparatus already available in the workshop and



Propeller No. 1; right hand.

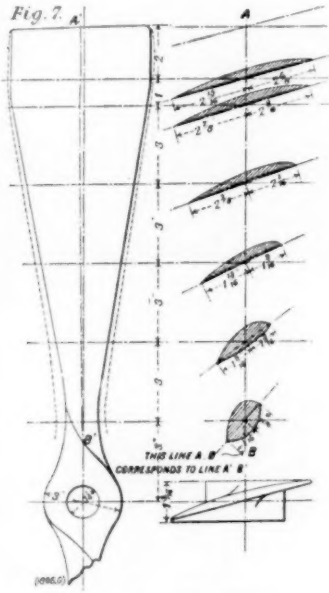


Propeller No. 2; right hand.

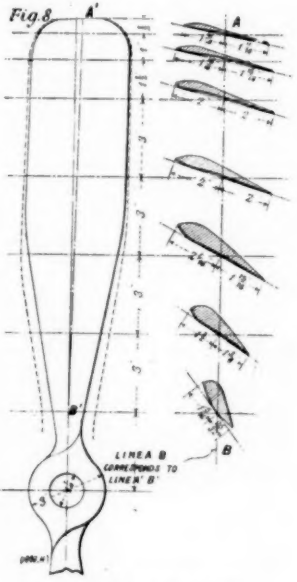
laboratory for other work was assembled and pressed into use pending the design and installation of a more suitable plant at a later date. It was thought that a few tentative experiments on this important subject would be of value as indicative of the line to adopt and the scope of work for future and more extensive research when the necessary funds are forthcoming.

The apparatus as erected and finally used for the purpose of these experiments consists, essentially, of a light steel shaft 1¼ inches in diameter carrying the propeller at its tail end

and driven by a 2-brake-horsepower electric motor (15 ampere, 100 volts) of the shunt-wound type mounted on a strong wooden framework. The shaft is supported in three plummer blocks provided with lubricators, the actual bearing area being small. The connection between the propeller shaft and the motor shaft is made by a coupling which permits of a free but small axial movement (see Fig. 2). A steel flange keyed to the motor shaft has three projecting pins which engage with corresponding holes in a flange keyed to the propeller shaft. These



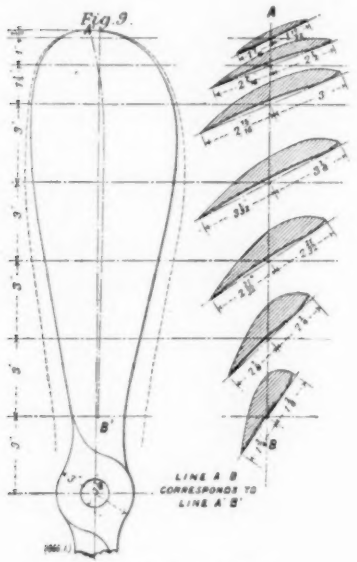
Propeller No. 3; right hand.



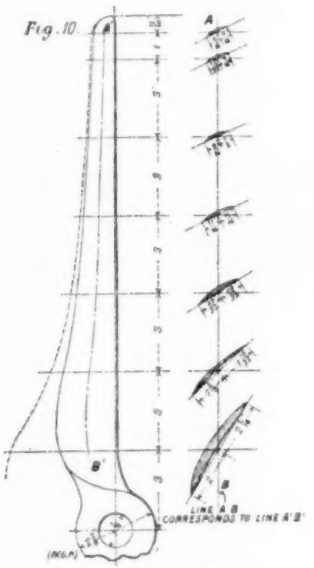
Propeller No. 4; left hand.

holes are slightly larger than the pins so that practically line contact occurs with the pins. The bearing at the propeller end of the shaft is supported on a light-metal framework so that the flow of air to or from the propeller, according to the direction in which it is rotating, may be influenced as little as possible. This precaution was found to be somewhat unnecessary, in view of the fact that a surface of almost equal diameter to the propeller caused practically no effect on the thrust even when brought quite close to the rotating propeller. The ap-

paratus was also erected as far as was necessary from both walls and floor of the laboratory to prevent any appreciable effect that they might have on the air currents. The thrust is taken and measured by means of a bell-crank lever for carrying the weights placed in a scale-pan, the vertical arm pressing on a ball-bearing thrust-block secured to the shaft, an arrangement which insures a minimum of friction (See Fig. 3). Weights are placed in the scale-pan hung from the horizontal arm to equalize the thrust. To prevent the shaft from having



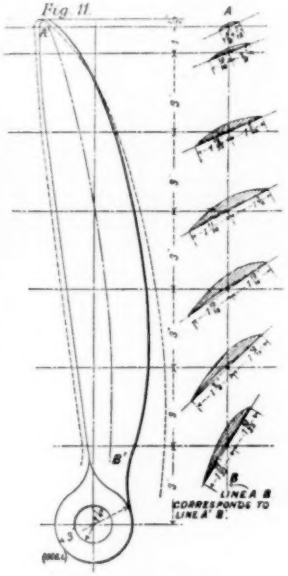
Propeller No. 5; right hand.



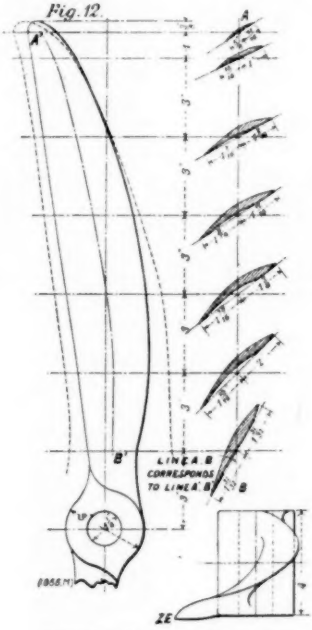
Propeller No. 6; right hand.

too great a lateral movement, and to provide a means for obtaining the necessary adjustment between the thrust and the balancing weights, a collar was fixed on the shaft on each side of the bearings allowing an axial movement of not more than ¼ inch. In the experimental determination of the thrust sufficient weights were added to enable the shaft to rotate with neither of the collars touching the bearing. In this position of equilibrium it was found that an addition of only 0.05 lb. was sufficient to disturb the balance, showing that the friction laterally during rotation was so small as to be negligible. The question

of static friction does not, of course, affect the case at all. The normal running of the motor was 1200 revolutions per minute but a large variation of speed was obtained by using in conjunction with the usual starting switch with five stops, an additional resistance frame with fourteen stops giving any range of speed required. An ammeter and voltmeter were also connected in the circuit. The measurement of the actual horsepower necessary to rotate the propeller at different speeds caused



Propeller No. 7; right hand.

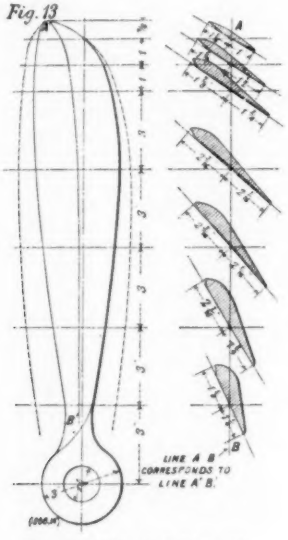


Propeller No. 8; right hand.

some little difficulty. The simple determination of the horsepower absorbed by the motor, as indicated from the instruments in the motor circuit, can only give an approximate idea of the horsepower actually absorbed by the propeller, owing to the great variation in efficiency of the motor when running at varying loads and speeds. To determine the horsepower with some degree of accuracy the following device was resorted to: A small cast-iron pulley was keyed to the shaft and a Soames band-brake used. During the measurement of the thrust given

by the propeller the brake was not used, but observations were taken for thrust, the amperes and volts as indicated by the instruments and also the speed by means of a direct reading speedometer.

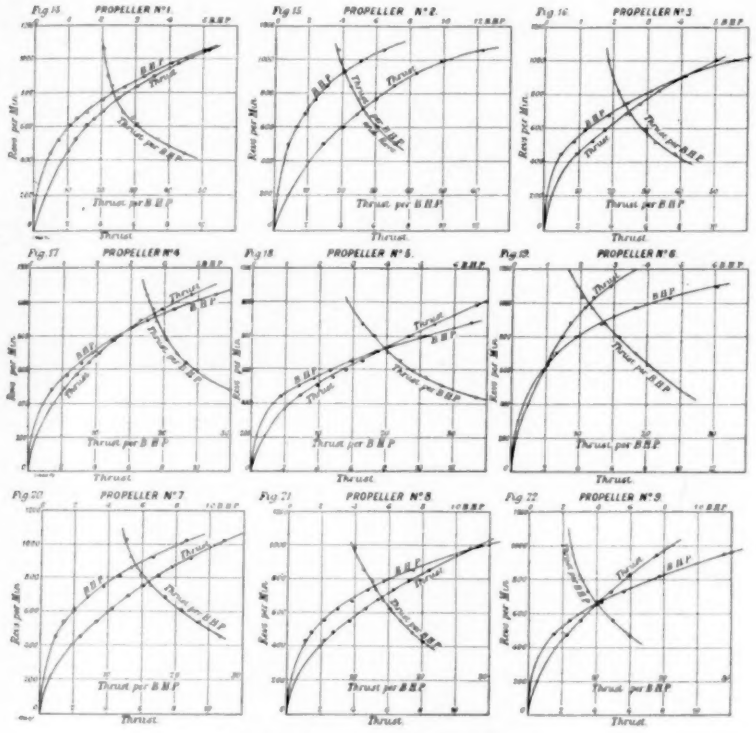
The propeller was next removed and the brake-band placed round the pulley and a careful adjustment of the load on the brake-arm made until the motor-instrument readings and speed were the same value as before. Although the reading on the voltmeter forms a direct means for ascertaining that the speed was the same as before, it was found advisable to again check



Propeller No. 9; right hand.

the speed with a speedometer, making any slight alteration of the brake load due to any small alteration of the voltage in the mains. To obtain the same resistance in the circuit for each of these tests, the position of the two switch levers was ascertained when making the first test and the same position used in the second test. To maintain the same frictional conditions, the load acting on the thrust bearing was kept the same in the two corresponding tests, and, to get over the difficulty of the pressure along the shaft not being balanced by the propeller thrust, and so causing one of the collars to press against one of

the bearings, the two flanges were clipped together so as to prevent the shaft having any axial motion, the collars being out of contact with the bearing. Under these conditions the efficiencies both electrical and mechanical must be the same in each case and the horsepower measured by the brake will be the actual horsepower measured by the propeller.



Results of tests of aerial propellers.

To obviate the necessity of double readings required by this method to eliminate the efficiency errors, it is suggested that a balanced motor be mounted on ball bearings and provided with an arm and suitable mechanism, by means of which the torque may be measured directly. This alteration would then have no need of great experimental manipulation to obtain good results, a point which is of some importance with aeronautical students who may not have had much laboratory train-

ing; at the same time the experiments could be carried out with despatch. Some form of dash-pot arrangement might be a necessity to damp any inconvenient vibrations which might

TABLE I.—PARTICULARS OF AERIAL MOTORS TESTED

No. of propeller	Diameter in inches	Projected area in square inches	Developed area in square inches	Pitch	Remarks
1	36.25	115	122	About 20 in. constant.....	Slightly concave driving face. Broad at tips. Corners left square
2	36	120	141	Constant pitch of 27.5 in. up to 15 in. radius, decreasing therefrom to 20-in pitch at tip	Concave driving face. Maximum width about two-thirds lengths of blade. Tips rounded off
3	36	107	118	Constant pitch of 27 in. up to about 15 in. radius, increasing therefrom to 28 in. at tip	Driving face almost flat; leading and trailing edges straight; and width constantly increasing to tip
4	36	96	110	Gradual increase of pitch from 25.5 at 6-in. radius to 26.5 in. at 14-in. radius, and a decrease therefrom to 22 in. at tip	Slightly concave driving face; leading and trailing edges straight; and width increasing to about half length of blade, followed by a constant width of tip
5	36	106	133	Gradual increase of pitch from 35 in. at 6-in. radius to 39.4 in. at 16-in. radius, followed by a rapid increase to 56-in. pitch at tip	Concave driving face; width increasing to about three-quarters length of blade; tips rounded off; plane of blade bent towards driving face at tips
6	39.375	56	66	Gradual increase of pitch from 34 in. at 6-in. radius to 37.5 at 16-in. radius, followed by a rapid increase to 60-in. pitch at tip	Leading edge straight; driving face slightly concave; width o blade decreases rapidly to about half length, then slightly narrows at tip
7	39	83	104	Gradual increase of pitch from 36 in. at 6-in. radius to 40.5 in. at 17-in. radius, followed by a rapid increase to 54.5 in. at tip	Usual form of blade, straight trailing edge; maximum width at half length and converging to a point at tip
8	38.75	89	102	Rapid increase of pitch from 38.2 in. at 6-in. radius to 72.5 in. at tip	Form of blade similar to No. 7
9	35.75	72	109	Increase from 60-in. pitch at 6-in. radius to 64-in. pitch at 12-in. radius, followed by a constant pitch of 64 in. to tip	Concave driving face. Usual form of blade converging to point at tip. Plane of blade towards driving face at tip

occur at high speeds but to what extent any vibration would affect such an arrangement is purely a matter for experimental investigation.

Propeller Forms.—All the propellers tested were made by the firm of Messrs. Handley Page, Limited, aeronautical engineers, of Creekmouth, Barking and 72 Victoria Street, S. W., and loaned to the authors for the purpose of these experiments by Mr. J. Handley Page. For convenience of reference, the principal details of the propellers are given in Table I while their exact forms are given in the illustrations (Figs. 5 to 13). Fig. 4 represents graphically the relationship between the radial pitch and radius for each one of these propellers. The projected area and the developed area for the several models are shown in the illustrations (Figs. 5 to 13), by the full thick line and the dotted line respectively, these areas for each blade being, in addition, tabulated in columns three and four of Table I.

TABLE II.—RESULTS OF TESTS

Propeller	1	2	3	4	5	6	7	8	9
1000 revolutions:									
Thrust	9.0	10.3	10.05	8.7	13.8	4.6	10.5	11.6	8.4
Horsepower	0.43	0.53	0.55	0.48	0.98	0.41	0.83	1.21	1.33
Thrust per horse-power	21	19.5	18.5	18	14.1	11.2	12.7	9.6	6.3
800 revolutions:									
Thrust	5.4	6.5	6.4	5.4	9.4	3	6.8	7.6	5.7
Horsepower	0.23	0.28	0.29	0.265	0.53	0.195	0.44	0.62	0.73
Thrust per horse-power	23.5	23.2	22	20.4	17.7	15.4	15.5	12.3	7.80
600 revolutions:									
Thrust	3.15	4.05	3.8	3.2	5.6	1.9	4.1	4.4	3.5
Horsepower	0.10	0.135	0.135	0.13	0.24	0.09	0.195	0.27	0.305
Thrust per horse-power	31.5	30	28.3	24.6	23.4	21.2	21	16	11.50

Test Results.—All the experimental results for the tests on the nine propellers selected are shown graphically in Figs. 14 to 22 and, in addition, tabular results are given in Table II, for three speeds—600, 800 and 1000 revolutions per minute.

Comparison of Results.—The best of the test results, considering only the thrust per brake horsepower are given as will be seen by reference to Fig. 23, by the propellers Nos. 1, 2, 3 and 4 with the small pitch angles and the greatest blade area near the tips. Propeller No. 1 has the least pitch which is practically constant; propellers 2 and 4 have constant pitch up to a radius of about 15 inches and then undergo rapid reduction of pitch, while propeller No. 3 has constant pitch up to 15 inches with slight increase near the tips.

If, however, results are judged from the consideration of

maximum total thrusts irrespective of horsepower, then propeller form No. 5 with the broad and more rounded blade and larger angle comes out the best, with the usual forms Nos. 7 and 8, coming next. The experimental results may be taken as some confirmation of the following theory:

In the case of a static test, the propeller blade meets the air at an angle which corresponds to the pitch angle while, in the case of a moving test, the angle of attack depends on the ratio between the forward and rotational velocities of the blade. Let

A = Area of small element of the blade which will be considered plane;
θ = angle of attack or pitch angle;
R = radius;
V = velocity in feet per second;
μ = coefficient of friction.

Then the forces acting on the small blade element are (1) a pressure P which assumes to be normal and is by Duchemin's law,

$$KAV^2 \frac{2 \sin\theta}{1 + \sin^2\theta};$$

(2) a frictional resistance which is assumed to act along the blade element and which will be equal to μP.

The thrust is the sum of the components of these forces at right angles to the plane of rotation and the pressure in the direction of motion is the sum of the components in that direction:

$$\text{Thrust} = P\cos\theta - \mu P \sin\theta$$
$$\text{Resistance} = P\sin\theta + \mu P\cos\theta.$$

The torque is measured by the product of the head-resistance and the radius and, since it is directly proportional to the horsepower it follows that

$$\frac{\text{Thrust}}{\text{Horsepower}} \propto \frac{P\cos\theta - \mu P\sin\theta}{R(P\sin\theta + \mu P\cos\theta)}.$$

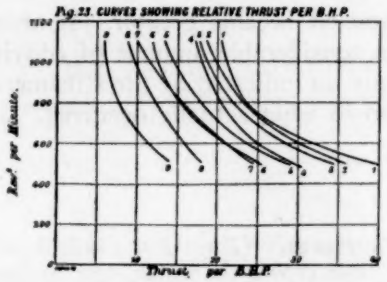
Dividing by P and *cos*

$$\frac{\text{Thrust}}{\text{Horsepower}} \propto \frac{1 - \mu P \tan\theta}{\tan\theta + \mu} \frac{1}{R}.$$

The expression decreases with increasing values of θ showing that the thrust per horsepower tends to decrease as the pitch or angle of attack increases.

It can be shown by differentiation of the thrust formula that the maximum thrust is obtained when $\theta = 35$ degrees, approximately, assuming μ to be small enough to be neglected. The maximum horsepower, obviously, is required when $\theta = 90$ degrees. An inspection of the test results for propellers Nos. 5, 7 and 8 will show that the mean value of the pitch angles for the important parts of the blade is about 35 degrees, and these are the propellers that give the maximum total thrusts.

In addition to the measurement of the thrust and horsepower, some experiments were made to determine as closely as possible the direction taken by the air thrown off by the propeller. To do this a light framework or cage of $\frac{1}{8}$-inch wire was constructed round the propeller, giving an all-round clearance of about 6 inches, and light pieces or streamers of silk thread



and ribbon were attached at suitable points. Considering the streamers across a diameter, it was found that they were strongly impelled outwards up to a point which corresponded to a distance of about 3 inches from the tip at which point the regularity of the flow was apparently much disturbed by eddy currents. Proceeding towards the tip these eddy currents gradually diminished and from the tip outwards and round the side of the propeller the streamers were drawn markedly inwards. There was also a tendency for the streamers to be inclined in the direction of rotation, indicating a certain amount of whirling action produced by the propellers.

At the back of the propeller the streamers were drawn in towards the propeller and the curious effect was observed that those streamers, for the last three inches of the blade and just beyond the tip were drawn downwards and pointed, roughly, to

a point corresponding with the point at which the outward flow ceased on the front of the propeller. This appeared to indicate that the last 3 inches of the tip had no effect as regards the thrust. It was also observed that the direction of the flow at the front was not horizontal but was inclined to the plane of rotation at angles which, apparently, had some relation with the pitch, being steeper towards the centre of the propeller where the blade has the greatest slope. Also the direction of the streamers placed on a circle was found to be towards a point which lay on the axis of rotation. Hence if a small element of length of the blade is considered, the air driven from it will move along a surface that can be compared to the surface of a cone whose apparent axis and apex are on the axis of rotation. The position of this apparent apex moved nearer to the propeller as the radius lessened and the angle at which the air was driven off became greater. It must be understood that there was a considerable amount of eddying and that the direction of the air, as indicated by the streamers, can only form an approximation to what actually occurred.

Bituminous Surfaces. (*Eng. Rec.*, lxii, 8.)—Bituminous surfaces should have less crown than macadam surfaces. While ¾ in. to the foot is customary for macadam roads, ⅜ in. or less is desirable on bituminous surfaces. Experience shows that roads made by mixing or grouting tar in the top course need a surface sealing coat, preferably of asphalt, for automobile and horse traffic, as that is less slippery, has a better appearance, and shows indications of a longer life than a surface coating of tar.

Fluxes in the Brass Foundry. EDWIN S. SPERRY. (*Iron Age*, lxxxvi, 3.)—A carefully considered paper, which will repay perusal. His conclusions may be summarized thus: For aluminum use zinc chloride; for nickel, use three parts of lime to one part of fluorspar; for copper, for copper castings use potassium ferrocyanide, but it is preferable to use de-oxidants, such as silicon-copper, magnesium and phosphorus; for brass or bronze use sodium chloride (salt); for German silver, use sodium nitrate and black oxide of manganese, also sodium chloride; for washings, grindings, etc., use plaster of Paris (calcium sulphate). In each case cover with coarsely granulated, not powdered, charcoal to prevent oxidation.

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